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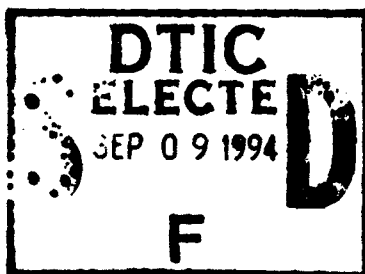


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**ARMY RESEARCH LABORATORY**



**Enhancing Soldier Performance: A Nonlinear  
Model of Performance to Improve Selection  
Testing and Training**



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13. ABSTRACT (Maximum 200 words) Advanced U.S. Army technology and hardware systems place a higher cognitive demand on the individual soldier than ever before. Sophisticated weaponry and hostile mission environments of modern conflict threaten to overwhelm the capacities of the human operator. New selection and training instruments are being developed to (a) select people most likely to perform well under high cognitive demands, (b) identify weaknesses in people, and (c) alter or train the person to improve response to the increased cognitive work load. The primary goals of this Phase I SBIR effort were to develop a new conceptual model and to suggest new testing and training approaches to handle the cognitive complexity of many Army tasks. Such approaches may enhance the identification and training of people to perform cognitive tasks efficiently during conditions of extremely high work load. To begin this process, a general "nonlinear" model of performance was first developed by exploring performance theory; this theoretical orientation was then translated into practical assessment and training tools to select and enhance people likely to excel at tasks demanding particular combinations of skills. A nonlinear approach to combining these procedures into a practical "test battery" and a specific training approach based on this model were proposed.  DTIC QUALITY INSPECTED 8				
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ENHANCING SOLDIER PERFORMANCE: A NONLINEAR MODEL OF  
PERFORMANCE TO IMPROVE SELECTION TESTING AND TRAINING

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Samuel Moise  
Debra A. Warner  
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July 1994

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U.S. ARMY RESEARCH LABORATORY  
Aberdeen Proving Ground, Maryland

## FOREWORD

This document represents the results of a Phase I Small Business Innovation Research (SBIR) effort directed at developing techniques to enhance soldier performance. The Contracting Officer's Technical Representative for this effort was Dr. Donald B. Headley, Human Research and Engineering Directorate, U.S. Army Research Laboratory.

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## EXECUTIVE SUMMARY

Phase I of this small business innovative research (SBIR) effort is an attempt to explore the potential applications of nonlinear "non-algorithmic" concepts to three diverse but related areas: performance theory, selection testing, and training. The effort is not directed toward exploring the mathematics or subtle theoretical nature of non-algorithmic techniques but to understanding how such techniques might contribute to the specified areas.

The best starting point for these explorations is the recognition that soldier performance in the future will demand more complex, higher level cognitive functions. Traditional deterministic, linear testing and training concepts are proving inadequate in handling such functions. Thus, if performance is to be enhanced, new areas must be explored.

Thus, a model of high level human performance was developed to serve as a foundation for interpreting selection and testing techniques developed later. This model postulates that performance in a given situation is the result of external stimulus demands passing through a series of individual analyzers that select resources to apply to the demands. The individual elements of the model are identified as (a) an energetic source, (b) an attention allocation function, (c) response domains or resources, and (d) the response mechanisms themselves. As with some traditional linear models, the individual elements are postulated to be interdependent. However, unlike those models, the elements are assumed to operate in parallel, and more importantly, their interaction is postulated to be probabilistic. Therefore, traditional deterministic solutions would not be expected to be efficient. This sets the stage for using non-algorithmic or nonlinear approaches to selection and training.

With respect to the development of an actual selection battery of tests, it is always possible, of course, to take a nontheoretical approach. This would select hundreds of potential tests and subject them to empirical, criterion-related validation. However, once a reasonable model is specified, it becomes possible to be much more selective in choosing candidate performance assessment methodologies, since only those capable of probing the various dimensions of the model must be included. In the present case, this exercise revealed a set of 24 candidate measures, which could be logically related to elements of the model. These measures theoretically probe the energetic, attention allocation, response domains, and the response itself with some degree of orthogonality. They are proposed as elements of a "generalized test battery," which can then be refined for specific applications. One such application is in the development of a set of specific selection batteries for Army tasks.

Based on the underlying probabilistic nature of the model, a nonlinear development of such selection batteries is described. Such development involves submitting the scores from the entire candidate battery to a neural net, for example, which would "learn" the optimum set of results and combinations to predict excellent performance in particular tasks. Such sets would then constitute criterion measures for that task, much as individual skill scores or linear combinations are used. Selection of those personnel showing the closest approach to the criterion sets would be expected to produce the highest performers in the task.

Finally, the same techniques are applied to the development of new training techniques. Two specific emphases evolve from this application. First, nonlinear procedures for determining specific deficiencies in a person are described. These nonlinear procedures involve the use of neural nets to determine combinations of processing characteristics that lead to optimal performance and subsequent assessment of a person against these criteria. Discrepancies are thus identified, and training goals are established.

The second specific emphasis is on the training itself. In line with the importance assigned to early, "intuitive" processes in the performance model, new techniques for training people in these processes are described briefly. Such techniques primarily involve driving the central nervous system to respond to time-urgent situations, which are carefully designed to make demands of each part of the overall processing sequence. These techniques are then used to train the person, using an on-line neural net technique to determine when training criteria have been reached.

Taken together, the model and specific techniques outlined in this report represent a first attempt to lay the foundation for next generation testing and training devices that surpass classical linear, deterministic models. At this stage, details about how these techniques can be applied are necessarily sketchy. However, the theoretical and rational foundation for their further development is compelling. The path for their further evolution and test is clear, and specific steps are outlined.

ENHANCING SOLDIER PERFORMANCE: A NONLINEAR MODEL OF PERFORMANCE  
TO IMPROVE SELECTION TESTING AND TRAINING

INTRODUCTION

The efforts reported here originated in the fact that high technology and hardware systems of the United States Army place a higher cognitive demand on the individual soldier than ever before. Sophisticated weapon system capabilities, coupled with hostile mission environments of modern conflict threaten to overwhelm the capacities of the human operator. Thus, it becomes increasingly important to define the internal state and trait variables that limit an individual's capacity to respond to increased cognitive task demands. If these variables can be identified and placed within a realistic and sufficiently robust conceptual model, it is possible that new selection and training instruments could be visualized and developed. The goals of these instruments would be to

1. Select people most likely to perform well during high cognitive demands,
2. Identify weakness in any given person, and
3. Alter or train the person to enhance his or her ability to respond to the increased cognitive work load.

The problem is that modern cognitive science is a relatively new and largely academically driven field (Gardner, 1987). Theoretical advances, while impressive, have largely been devoted to microscopic examination of the process of cognition--in many cases from trying to create a mathematical computer model of the process. These efforts may one day lead to a fuller understanding of the entire cognitive process. For the moment, however, they have not produced principles that can be easily applied to the incredibly complex performance environments in many real-world tasks--most notably for the present purpose, in the combat tasks faced by the Army.

The traditional approach in cognitive psychology has been to develop linear, algorithmic models that try to weight and combine individual skills into descriptions of the performance requirements of complex tasks (see Analytical Assessments Corp., 1988, for an excellent example of this approach). These efforts have met with considerable success. However, as Sheridan (1991) has pointed out, "...as technological systems become bigger and more interconnected in terms of people, computers, and expenditure of community resources, the simpler one-person stimulus-response interface questions seem to become less important and...other, mostly "softer" issues, more important. Mathematical models that serve well for simple manual tracking, signal detection, or immediate memory seem totally inadequate to multi-person distributed decision making..." De Greene (1990) goes even further, suggesting that the Newtonian paradigm, which has dominated Western scientific thinking, may be inappropriate in many research situations. This paradigm requires a reductionistic approach which involves "...the identification of parts and the causal connections between parts as the means of system understanding." It assumes that the determinants of causality can theoretically be defined, and in that case, prediction would be perfect. Meister (1991) points out that complex real-world systems frequently do not fit the Newtonian criteria (e.g., those with little proceduralization, great response flexibility, high ambiguity, imprecise feedback, etc.).

In fact, combat tasks can be seen as particularly inappropriate targets for reductionistic, linear theories (e.g., see Hedgepeth, 1993, for an excellent discussion of this theory relative to military operations research). Many Army tasks today fit Sheridan's description precisely. They are multiply determined at best and at worst have an almost prohibitively large number of variables interacting in complex ways. In spite of this, however, selection and training of combat soldiers, development of combat doctrine, and a host of other problems are real, present, and critical issues today. If the field of cognitive psychology cannot address issues of this complexity, then it is certain that the void will be filled by guesswork and intuition.

The primary goal of this Phase I small business innovative research (SBIR) effort was to develop a new conceptual model and to suggest new testing and training approaches, which might be robust enough to handle the cognitive complexity of many Army tasks. Such approaches should then enhance the identification and training of people who show capabilities to perform cognitive tasks efficiently in the face of extremely high work load.

To begin this process, a general "nonlinear" model of performance was first developed, using elements of several previous models. This development was accomplished by exploring past and current concepts in performance theory (see Appendix A). Admittedly, this research was an attempt to explore the outer boundaries of cognitive psychology's contribution to an overall theoretical approach explaining highly complex performance.

A second but no less important goal of the present effort was to translate this theoretical orientation into practical assessment and training tools for the selection and enhancement of people likely to excel at tasks demanding particular combinations of skills. A relatively exhaustive list of test procedures that might be used to probe these skills was developed, and a nonlinear approach to combining these procedures into a practical "test battery" was suggested. Finally, a specific training approach, based on the model developed, was suggested.

## A MODEL OF COMPLEX PERFORMANCE

The goal of the present section is to develop an outline of a performance model, which will lend itself to the development of tests and training techniques for the Army. Thus, the following exposition is not cast into an academic or basic science format. Arguments about whether a particular element of the model fits best before or after another element are important in the present context only if the answer affects final performance. Similarly, experimental predictions generated by the model, while interesting and eventually important, are ignored unless they affect the overall goals of the present effort. This section discusses specific aspects of other models, especially the interactive process model of Secrist (1988), and focuses on describing some of the interactions of those models. In view of the limited scientific scope of this effort, therefore, although the term "model" is used throughout this work, it may be more scientifically accurate to consider it a general "framework."

### Overview

The basic postulate of the present model, in line with many current views, is that performance in a given situation is the result of external stimulus demands, which pass through a series of "analyzers," resulting in the

selection of certain "resources," which are then applied to respond to those demands. Energy for these activities comes from metabolic processes that activate specific physiological mechanisms. This whole process is seen as operating in parallel and in a probabilistic way. In this sense, it resembles a nonlinear network.

The model developed here is similar in many respects to the connectionist theory described by Shastri, Lokendra, and Feldman (1986). This theory proposes that massively parallel or connectionist processes, modeled as neural nets or semantic networks, describe human cognition and perception in physiologically plausible terms. In this view, connectionist networks are seen as consisting of active elements, each capable of performing simple processing. An element's potential, or output, depends upon the activation it receives from other units (Shastri et al., 1986). The model developed here postulates that these "units" consist of specialized filters tuned to specific sensory and perceptual characteristics of a stimulus situation. They resemble the "frames" (complex packages of knowledge that describe an object or concept) postulated by Minsky in 1974 (Grunwald, 1986). These frames enumerate attributes and associated values, and each simple frame may be interlocked within far more complex interlocking structures of knowledge nested in larger frames.

The present effort argues that such elements emulate "filters" and "decision points" in a general performance model. Each unit communicates with the others by transmitting a level of energy to those units connected to it. In other words, stimulus characteristics are processed in parallel at a series of probabilistic "nodes" or first level filters, which output a certain "weight" of energy, depending on the strength of those filters' stimulus characteristic. This weight is then passed to a set of higher order nodes, along with the simultaneous outputs of all other first level filters. These weights then influence (again, in a probabilistic way) the output of second level filters, which are conveyed to an even higher order filter process. After some finite number of such iterations, the final filter output determines both the short- and long-term use of resources to produce a response to the stimulus. In the performing human, these processes take place in a matter of milliseconds--with a total time of 500 milliseconds representing a long response in many cases.

The preceding overview does little to define the actual filters, processes, and resources that might exist. This definition is outlined in somewhat greater detail in the following paragraphs. For the present purposes, however, the specific processes and resources that are presented are independent of the overall framework. The specifics may continue to be modified without changing the basic framework. This model should be robust enough to accept additional specification. As such specification improves, better predictions about testing and training should become possible.

Now that some general principles for the model to be presented have been established, the details and implications of the full model will be explored. Essentially, the entire model has three major processing sections and a final response section. The first processing section concerns the energetics of the overall system and discusses factors that modulate every subsequent function, node, and resource. The second section concerns the attention allocation aspects of the system. The attention allocation process means that the stimulus situation is processed by the various levels of filters, and the resulting weights are determined. Based on the results of these attention

allocation processes, the overall methods or resources that will be used in responding to the stimulus demands are selected and implemented. These responses constitute the third section of the model.

### The Energetic System

At the most basic level, the first requirement for any model of human performance is to provide a driver mechanism. This consideration has been ignored in many previous models of performance. However, other authors have acknowledged the importance of considering available energy (Humphries & Revelle, 1984; Sanders, 1983). Kahneman's capacity model (see Appendix A) postulated that resources are limited by the person's level of arousal, in the form of effort and attention, which are controlled by feedback from performance. Similarly, the cognitive-energetic-stage model (Gopher & Donchin, 1986) used terms such as motivation and situation assessment to describe the determinants of the activity of three main energetic generators: arousal, activation, and effort. This model suggested that the energy state could have different effects on response domains, a position held by the present model. Finally, one of the most complete explorations of energetics in performance models has been presented by Hockey, Gaillard, and Coles (1986).

The basic formulations are consistent with the present model. The function of the energetic system is to provide for the overall activation of the person, based on his or her goal orientation and metabolic state. The level of energy supplied by this system determines how subsequent filters will operate in terms of sensitivity, power, speed, intensity, and other characteristics of the response domains. The postulated components of the system are depicted schematically in Figure 1.

The basic component is the metabolic status of the person (see (1) in Figure 1), which provides the energy available for interacting with the environment. In other words, even at this very basic level, a person's ability to perform in the face of internal or external stresses may be attributable to subtle differences in available energy and mobilization for a given task. This component is a key starting point for the present model. It postulates that small differences in the amount of energy available and in the way a person employs the available pool of energy may have vast performance implications later in the processing sequence. As discussed further in this report, this component provides the first clue regarding human aspects to be measured, evaluated, and perhaps altered in the person performing a demanding task.

Available evidence indicates that there are ample opportunities for people to differ in their energetic response to specific task demands. For instance, positron emission tomography (PET) scans suggest that certain brain areas may increase oxygen metabolism in response to unique task demands (Hockey et al., 1986). It is reasonable to hypothesize that people differ significantly in such oxygen mobilization, and assessment of those differences may be an important (and often neglected) aspect of selection tests.

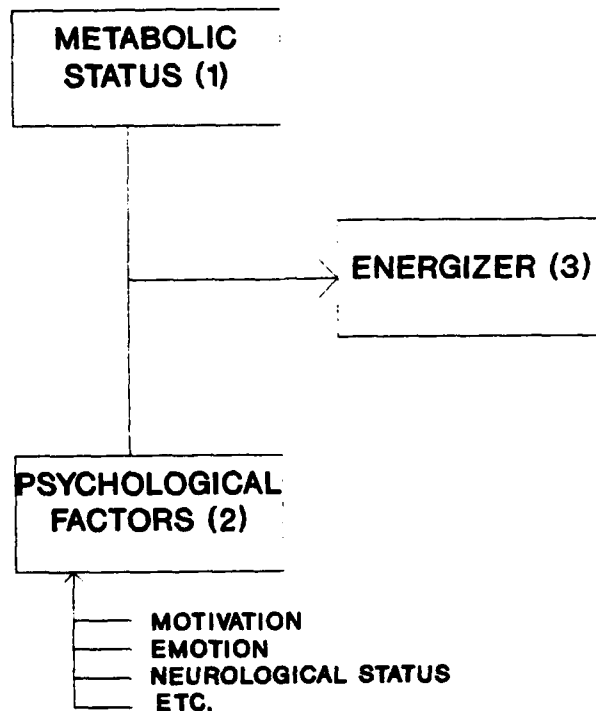


Figure 1. The energetic system.

One can proceed one step further and ask what determines this metabolic energy level--what determines individual differences in this system? Either something inherent in the stimulus configuration increases metabolism, or such cortical energizing is controlled by a second mechanism.

In the present model, the latter situation is postulated. Complex "psychological" factors (see (2) in Figure 1) are assumed to operate on the basic energy available and to modulate the amount of energy that will actually be used for the task. This modulator not only affects energy level but also provides directionality to the ultimate behavior. In essence, a reciprocal relationship is postulated in which the basic energy pool available to the individual is allocated to specific task demands based on the person's psychological state. This state is determined by all the cognitive factors that cause a person to adjust the energy devoted to a task: past experience, time spent on the task, criticality of the task to survival or motivational levels, even inherited sensitivities and levels of neurotransmitters circulating in the system. Acting together, these factors ultimately set limits on the amount of energy that can be made available at each subsequent "node" in the system (see (3) in Figure 1).

This view is somewhat different from many current approaches to cognitive performance. It places "psychological" factors very early in the processing sequence and opens the possibility that such factors may operate at a more primitive (unconscious) level than is sometimes thought. This observation raises an interesting and rather revolutionary possibility with respect to training. Even when the goal is to increase the person's capability to perform in extremely complex environments (i.e., to enhance work load capacity), it may be desirable to focus training on the "primitive" energetic component of the system! As will be seen, this suggestion forms a pivotal consideration for the proposed training system.

In general terms, the optimal amount of energy that should be made available for a given task has received much attention in the literature (Hockey, 1986). This resulted in the popularized wisdom that an "inverted U" function best describes the arousal or performance relationship. In this view, optimal performance is achieved at some intermediate level of activation, with poorer performance at both low and high levels of activation. However, it has long been recognized that the simple "inverted U" function must not ignore task difficulty. In fact, as early as 1908, the fact that optimum arousal is inversely related to task difficulty was formalized in the famous "Yerkes-Dodson law" (Yerkes & Dodson, 1908; Easterbrook, 1959). Secrist (1988) has concluded that different "internal states" of arousal are optimal for certain kinds of information processing. For instance, a state of "relaxed attentiveness or mental quietude" may facilitate high speed processing, while slower, more reflective processing is best performed at a state of moderate arousal. This is, of course, an empirical question beyond the scope of the present effort. However, the energetic system as described here provides the framework and perhaps the mathematical structure for interpreting and integrating the empirical data.

In summary, the proposed model suggests that even complex performance may be crucially influenced by subtle individual differences in the energetic system. By energizing (or failing to energize) subsequent filters, a person could "succeed" or "fail" a task. A failure might appear to be attributable to inadequacy of a resource or skill when the failure was actually assured much earlier in the processing sequence.

#### The Attention Allocation System

Performance theory has often confused the concepts of "skills" and "skill use." The assumption has been that because a person possesses a skill, performance of tasks demanding that skill will be good. Many selection tests in existence make this tacit assumption, but it is not always true. Skill use in any given context depends not only on the absolute amount of a resource available to the person (and on the energetic conditions present) but also on another intervening variable. This variable involves the person's ability to appropriately distribute attention and resources to respond to the present task. It has been variously described but is best termed the attention allocation system.

The notion that attention allocation may constitute a separate and trainable resource has received considerable speculation. This speculation arises from the observation that extensive practice of initially overwhelming dual tasks can ultimately produce performance of both tasks, which approximates performance of each alone. This result occurs whether the dual tasks make demands of the same resource or of separate resources. The subject must be "learning" something, and the available data indicate that the "something" consists of strategies for integrating (or multiplexing) the dual tasks into a more efficient unit--an attention allocation strategy.

Recognition that attention allocation can be treated independently of the skill or resource being used opens some new theoretical considerations, as well as new testing and training domains. The concept suggests that each individual skill or resource can handle a much greater volume of task loading than it normally does, and the attention allocation resource frequently limits human performance. In view of this, a large section of the present model is devoted to the hypothesized mechanism of attention allocation. The attention allocation system of the overall model is illustrated in Figure 2.

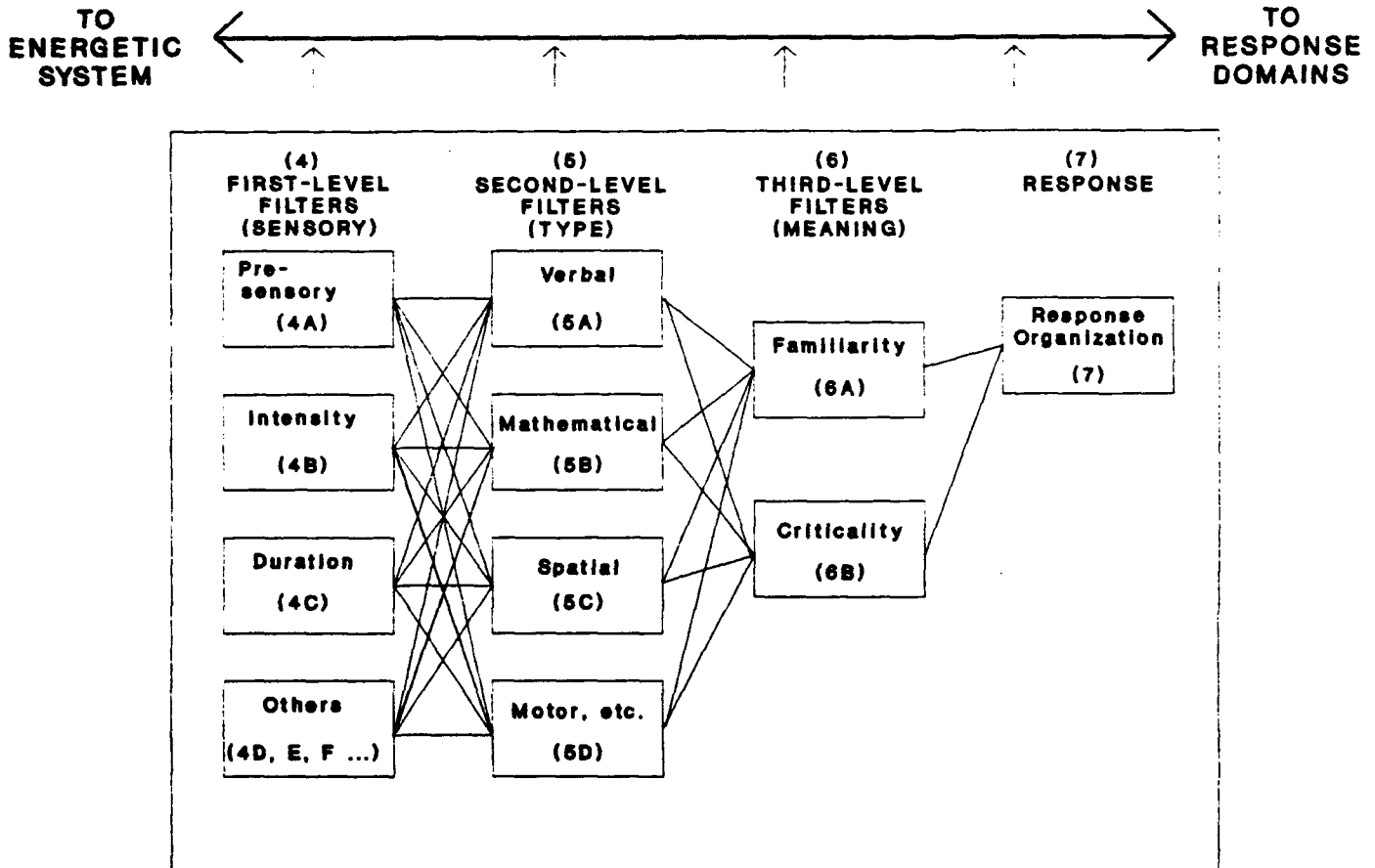


Figure 2. The attention allocation system.

The system is postulated to contain a number of filtering levels (see 4, 5, 6, 7 in Figure 2) (described in more detail in Appendix B) that proceed from basic to more complex stimulus characteristics. First level filters (see (4) in Figure 2) concern absolute physical characteristics of the stimulus (intensity, contrast, brightness, etc.), and these filters are processed first. Second level filters (see (5) in Figure 2) compare these physical characteristics to past experience. This comparison may be done by a process of simple "template matching" (see Appendix A). This theory proposes that incoming stimuli are continually compared against stored codes, or templates.

These filter levels continue, with each subsequent level performing a "higher level" of comparison. For instance, a third level of filtering (see (6) in Figure 2) may perform semantic comparisons (and potentiation) of the kind proposed in the Attenuation Model of Treisman (Matlin, 1989) or the Pertinence Model of Norman (Solso, 1979). After some number of such filters, if there is sufficient certainty about the stimulus and response conditions, a response can be executed.

The present model proposes that the energetic system "presets" a certain threshold level for each of the filters shown in Figure 2. For every stimulus, one of three events is possible. First, if the incoming stimulus fails to meet the threshold conditions, the filter fails to "fire," and that characteristic of the stimulus is not perceived. Second, if the incoming stimulus exceeds the threshold, the filter "fires" with a certain output value to the next levels. This value is proportional to the degree of mismatch between the filter's maximum preset value and the input stimulus. In this way, "decisions" by the system result in finer and finer (more "cognitively sophisticated") distinctions concerning the appropriate response to the environment. The third condition occurs if the stimulus characteristics match preset levels perfectly in a number of characteristics. If this perfect matching occurs, the output at any level of filters can bypass all later levels and be passed directly to response sections of the model (noted by the arrows that can go directly to the response). This characteristic explains the development of "automatic" behavior or "privileged loops."

Figure 2 provides for a "feedback" loop from each level of the attention allocation system (4, 5, 6, 7, etc.) to the energetic system (3). Such feedback probably operates continuously to "fine tune" the energizer to the current status of the stimulus environment (i.e., adjusting energy expenditure to environmental demands). It is absolutely necessary that such feedback operate effectively in situations of high stress, high work load, ambiguity, or danger. In such cases, if the stimulus environment is not providing sufficient cues, it is essential that the energetic thresholds be changed. Conversely, if a person is overwhelmed by the stimulus-response environment, the trigger levels of each filter can get too low, processing becomes jumbled, and panic or "spastic" behavior results. The energetic system has simply lowered thresholds to the point that irrelevant amounts of energy at first level filters may trigger an entire response sequence.

The opposite situation may also occur and unfortunately seems to occur often. Such would be the case if, during an extremely stressful situation, the trigger levels of several filters were raised to levels at which they could not realistically fire. This behavior results in the familiar phenomenon of "channelized attention," in which the person becomes so focused on a few aspects of the environment (e.g., the pilot on an attack concentrating on speed, attack angle, weapons sequence, etc.) that other critical information is "ignored." In terms of the present model, the energetic component (driven by goals and other psychological determinants) sets the threshold levels of some attention allocation elements very low, while setting others at unrealistically high levels. Thus, critical information (such as radio calls) may not be processed beyond the first or second level filters.

As noted, communication from each stage of early filters may bypass other filters and go directly to response. This process is postulated to account for "automatic" behavior, as described in Appendix A. If, at any stage, a match that occurs between current and stored memory is so strong (has had such a consistent history of one-to-one mapping) that it produces an extremely high output value, a "privileged loop" (McLeod & Posner, 1985) is created. Such a loop bypasses further filtering and enters directly into subsequent stages at a level determined by the intensity of the output.

Generally, the results of third level processors are seen as feeding directly into a final stage of attention allocation (see (7) in Figure 2), which begins to organize the response. This "filter" is seen as differing somewhat from previous ones, in that it compares the entire composite of

incoming energy levels with composite response sequences available to the person. In other words, this stage matches "what is required" from the person with "what is available" within the person. If a reasonably good match occurs (i.e., there has been a considerable history of one-to-one matching between those stimulus conditions and a particular response sequence), that response sequence is initiated, and processing proceeds to the next level. If no match occurs (i.e., the conditions are totally novel, unexpected, or contradictory), either no response is initiated or random responding results. If, as is most often the case, a partial match is made (i.e., the stimulus condition could map to one of several different response sequences), then one or several response sequences could be initiated (depending, at least, on the ambiguity of the inputs). These sequences are passed to subsequent processing levels, which then have added responsibility for eliminating the more inappropriate responses and performing those that most probably are appropriate. Such ambiguity, of course, adds time to the processing or response sequence and therefore leads to higher work load.

Parenthetically, the model provides a potentially productive way of viewing "situation awareness." As long as the input to the attention allocation (see (7) in Figure 2) filter is the result of appropriate processing at each of the previous filter levels, the "situation" will be represented accurately at the final filter, and the person will be "aware" of the situation. If an appropriate response sequence to that situation is already established, it will be initiated. To the extent that the attention allocation system as a whole has failed to register some aspect of the stimulus environment, input to the final filter will be distorted, and an inappropriate response will be selected (or none at all). The person would then be said to display poor "situation awareness."

Some time has been spent discussing these "primitive" processing stages to emphasize the fact that such "unconscious" functions have a massive effect on the quality of subsequent processing. Yet, few training or testing programs are directed to assessing or enhancing such processes. As will become evident later, it is a basic premise of the present effort that significant improvements in cognitive function can be made at this stage through training.

### Response Domains

To this point, the model has involved the person's ability to analyze the environmental situation and to prepare a response plan for that environment. The response plan has presumably been initiated, based on the person's assessment (not necessarily conscious) of the available performance capabilities. It now remains to specify the nature of that plan, which is seen as consisting of two major categories of process. The first selects certain generic categories of activity, and the second selects specific performance resources to perform those activities.

As shown in Figure 3, two major response domains are postulated. One consists of "intuitive" processes (8), and the other consists of "reflective" processes (9). Intuitive processes (first described by Secrist as "HP-I" processes) involve urgent, high speed information acquisition and processing and anticipatory behaviors operating on near threshold visual-spatial or pattern information (Secrist, 1988, 1990). Task requirements and behaviors of the intuitive domain have a number of salient distinguishing characteristics:

1. They generally occur within the context of temporal urgency with respect to time available for information acquisition, processing, and decision making;
2. The information content is usually spatial or patterned;
3. Anticipatory judgment is crucial; intuitive decision processes are accentuated; and
4. Dire consequences often result from incorrect decisions.

Conversely, reflective processes (sometimes called HP-II responses)

1. Involve information acquisition, processing, and decision cycles that are not typically urgent;
2. Involve information content that is predominantly verbal and symbolic;
3. Require abstract thinking; judgments tend to be contemplative; and
4. Involve decision algorithms that are more analytical and deliberate.

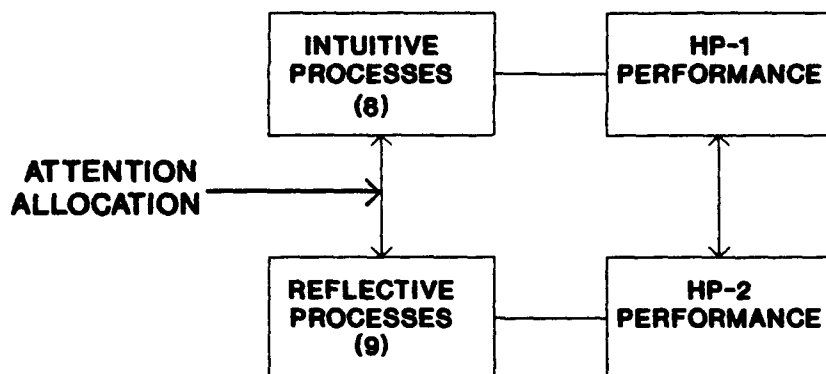


Figure 3. Response domains.

The differences between these two types of processes are described more fully in the following paragraphs. Although they show considerable amounts of interdependence, these domains can be studied in relative isolation, at least with respect to their appropriate spheres of control, their anatomical bases, optimal internal states for their execution, and training tactics.

#### Intuitive Processes

At their most basic level, these processes "acquire, analyze, process, and produce responses to sensory stimuli near, at, or below the level of conscious awareness" (Secrist, 1988). These characteristics provide some

important clues regarding the underlying physiological and functional nature of this type of processing. First, since stimuli are usually near threshold, it follows that these functions have traditionally been examined from the viewpoint of sensory organ limitations. Psychophysical "thresholds," at least until more recent times, were conceptualized as pure sensory limits. More recently, it has become generally accepted that subtle variations in higher cognitive processes may significantly affect a measured threshold (Green & Swets, 1966). Thus, in the present model, these processes, at the final performance level, are placed well after the many "psychological" determinants (block 2 of Figure 1) of traditionally considered "sensory" thresholds. These processes will not be understood by reference to sensory organ physiology alone.

A second observation stems from the predominantly spatio-temporal nature of the stimuli. Physiologically, such functions have been conceptualized as residing primarily in the "right side" of the brain. Stated more precisely, with the proper spatio-temporal stimuli, certain analytical, verbal "nodes" can be bypassed, and classification, decision, initiation of action, and coordination of such action can take place without the necessary intervention of "higher" cortical centers concerned with more deliberate, analytical processes (i.e., much of the sub-cortical and motor cortex response execution is performed without "conscious" decision).

Even for nonspatial activities, intuitive processes may play a significant role. The demonstration by Chase and Ericson (1980) of a remarkable capability to develop a verbal memory and recognition skill is significant. Their concept of skilled memory suggests that certain well-practiced and well-mapped skills can be performed with amazing speed and accuracy. Thus, people may be able to use intuitive processes even for tasks that are usually considered highly reflective. Apparently, skilled memory permits extremely fast storage and retrieval of specific information without reference to short-term memory. Again, this concept is reminiscent of McLeod and Posner's (1985) "privileged loops," which permit direct response initiation without the need for the usual intermediate processing.

In the present model, it is postulated that if specific combinations of outputs from the attention allocation filters result in an "intuitive" processing domain being chosen, the response outcome is virtually determined, the response occurs rather rapidly, and overall work load is reduced. Once this result occurs (either through the entire attention allocation process or through a privileged loop), the final behavioral response is accelerated through a principle of "minimum resource use." That is, the fewest and least complex resources are used to respond to the environment. Thus, if the intuitive processing domain is activated, then all well-practiced response repertoires are activated (using all the established scripts in skilled memory), and the most appropriate and efficient one is initiated.

On the positive side, this process results in the fastest response with a reasonably high probability of success in the task. On the negative side, it results in a "dumb" response that is not reflectively considered at each stage of processing and which, once initiated, is difficult or impossible to correct or cancel. Again, this process corresponds to common experience, usually in a competitive sporting situation. Most people have initiated a response, based on some criterion goal, which (even before the result was known) they wished they could cancel but could not.

## Reflective Processes

The temporal or energy level of the stimulus again is used to characterize reflective processes. If the output of the attention allocation filters suggests that the stimuli are at supra-threshold levels of time and intensity, and if the response demands permit (the restraints being that response times greater than 500 to 1000 msec are usually considered normal or acceptable), then this response domain will be selected. In addition, stimulus content is also critical in determining whether this type of processing will be used. These classes frequently involve verbal or highly symbolic stimuli, those that require "cognitive" processes involving active memory, complex relational transformations, classification, processing according to some symbolic or even arbitrary rule, and response selection which may or may not be compatible with the stimulus configuration.

From a traditional cognitive sense, these operations can be considered deductive, analytical, or contemplative rather than inductive and anticipatory. The stimulus content, being symbolic, is most often an abstraction in itself, as opposed to the more concrete stimulus meaning with intuitive processes. This type of process may be considered to be more "advanced" in the sense that it less directly concerns immediate survival but involves conscious attentional resources, long-range planning, and decision processes that are more contemplative, less temporal and spatial, and more overtly categorical.

In the present model, it is proposed that the output of the attention allocation system is a "plan" that calls for the use of one or both domains of performance (the intuitive and the reflective) in some combination to optimize performance. Depending on the particular combination of intuitive and reflective processes chosen, a unique combination of verbal or spatial resources and long- or short-term memory resources will be employed (along with the motor resources necessary to implement them).

### Summary: The Overall Model

All the elements described separately are shown in Figure 4. The authors have tried to provide a framework that specifies the processes and rules that guide the human from the first encounter with the stimulus environment through the development and final implementation of a plan to respond to that environment. This process has several general characteristics: first, it is reductionistic in that "features" of the environment are separately analyzed and evaluated. Second, it is goal directed, and such goal orientation operates at the level of overall energy allocated to the task and at the level of specific "decisions."

Third, it is postulated that the system operates in a nonlinear, probabilistic way and that it can probably be modeled through available nonlinear approaches. This third characteristic provides the most innovative aspect of the present effort and sets the stage for the specific selection, testing, and training techniques proposed here. To this point, it might still be argued that the proposed model could be considered absolutely deterministic (for any defined set of inputs, there should be a perfectly defined set of outputs). However, rigid adherence to the deterministic approach has led to significant problems in ergonomics (O'Donnell, 1991a). Human behavior appears to defy deterministic analyses. Thus, the proposition is made here that the filters in the present model act in a probabilistic way, much as neurons appear to act at synapses. Extremely small variations in initial conditions can have extreme effects on final performance. Two apparently identical environmental configurations reaching a particular filter under apparently

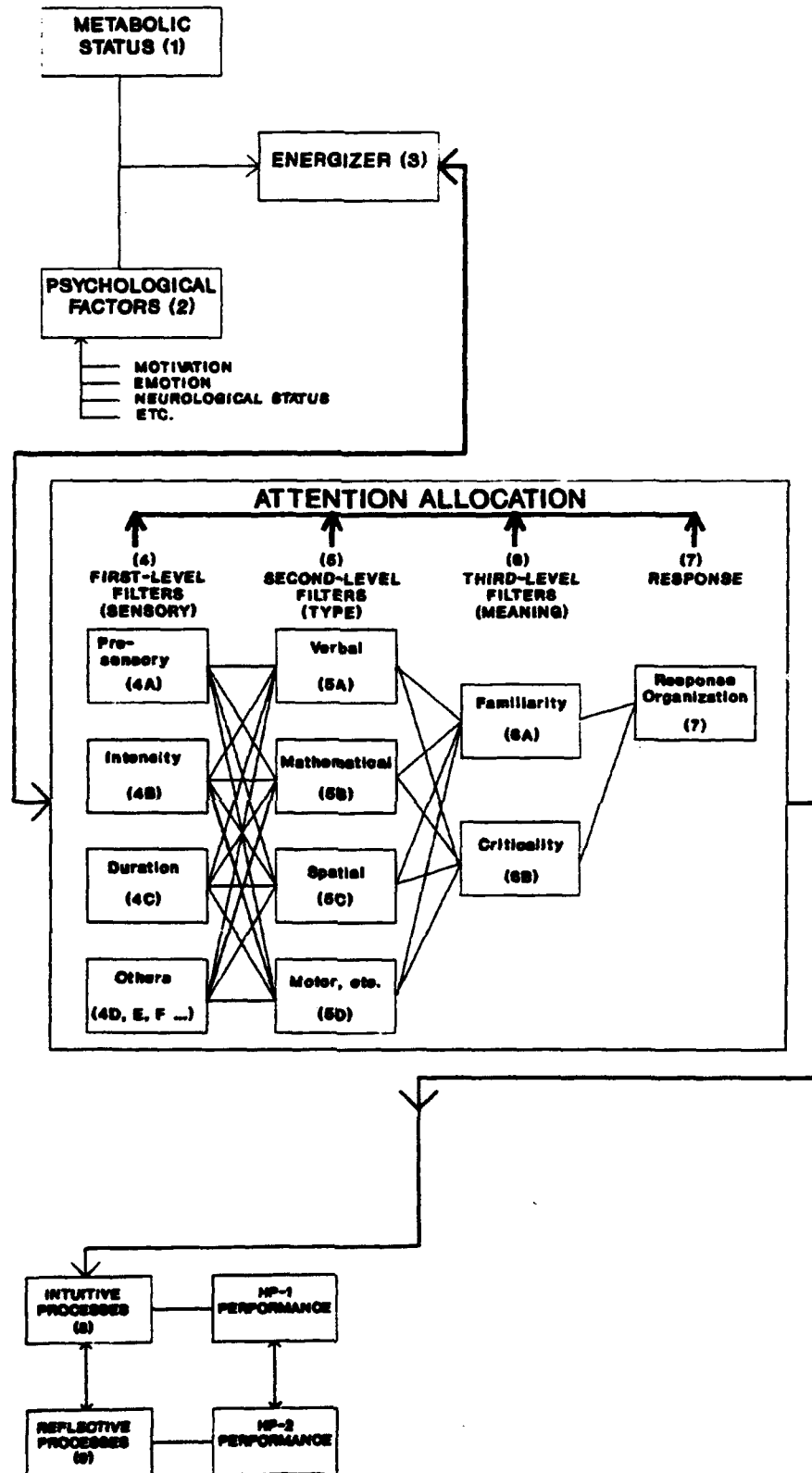


Figure 4. The overall model.

identical energy configurations and goal orientations will not always produce the same output!

Further, outputs from every node may differ quantitatively for any given iteration, even for the same input configuration (although they will probabilistically tend toward the ultimate goal). In addition, outputs from any given first level node may activate a second level node or inhibit it. For instance, the output of the "intensity" filter might be so low that the second level nodes are inhibited completely. In that case, the output from all the second level nodes might equal zero, which (usually) will inactivate the system (and subjectively result in the stimulus never reaching conscious awareness) even though some processing has been done. The system rapidly becomes so complex that an algorithmic solution to this model would be extremely difficult.

Mathematically and logically, however, the situation is not as intractable as it might first appear. It is perfectly legitimate to propose that, probabilistically, the output of each filter will tend toward greater goal achievement (i.e., the system will "learn" what its goal orientation tells it to learn). Thus, the entire system may be seen as deterministic but not predictable in any absolute sense.

This observation, of course, suggests that an appropriate mathematical technique for conceptualizing and analyzing the entire process is neural net technology. The output of each filter is sent to every subsequent filter, and the "response" of this latter filter is some result of the combined weights of the inputs. Even more sophisticated nonlinear approaches might be applied to this model.

This theoretical view raises exciting possibilities for using neural net approaches to the definition of "optimal" outputs for each filter. For instance, complex tasks could be simulated on a computer, and their stimulus environment could be "fed" into a neural net. Using a criterion of excellent performance, the net would iterate various values for each filter node until it reached an "optimum." Presumably, the combination of output values that was practically achievable by a human would then define the selection and training "goals" for that complex task. In other words, instead of simply measuring "skills" in the person, on the assumption that the person possessing the "most" will be the best, this approach would clearly define an optimal combination of energetic states and attention allocation nodes for any task. Selection tests and training regimens could then be built around these states and nodes, rather than being based on skills alone.

In even more practical terms, one might consider the potential for the approach to respond to the "selection ratio" at any given time. In peacetime, an all-volunteer force is recruited to respond to an amorphous potential threat. During these conditions, "excellent performance" can be defined with much more rigorous criteria. In other words, with this select force and a reasonably casual time press, one could hold the prospective candidate to extremely high criteria. This strategy is analogous to a sports team that is already the best and has all positions filled with excellent players. Such a team can be highly selective and can concentrate on general criteria of the "best athlete," rather than search for the best person in a given position. Thus, during these conditions, the present model might increasingly employ physiological, energetic, and HP-I criteria, rather than focus on specific HP-II skills. In a rapid wartime buildup with a large drafted population, however, the need would be to search for people who have the optimum combination of HP-II and other skills now. Obviously, the model could

accommodate these different requirements . / simply changing the criteria or reference group against which test results are validated. In either case, the nonlinear analysis would presumably reveal the optimal set of scores for the given criterion.

Specific concepts for implementing this approach within the framework of the model are presented in the following sections.

#### A CANDIDATE PERFORMANCE ASSESSMENT BATTERY AND ITS NONLINEAR VALIDATION

A goal of the present effort was to select a set of existing performance tests that correlate, as closely as possible, with the model presented in the previous section and can therefore be related to Army tasks. In other words, the model was used as a "bridge" between basic skills or functions probed by each test and those required in Army-relevant tasks. This approach represents an extension of traditional test battery development procedures, rather than a replacement of them. In such procedures (e.g., Analytical Assessments Corporation, 1988; Carretta, 1989), the goal is to isolate tests that probe either "skills" or "functions" relevant to tasks. Such a goal also exists in the present case. However, the significant difference is that the mechanism for combining such skills or functions into complex performance is part of the underlying model, and that mechanism is postulated to not be additive or even linear. The present approach should succeed better than its predecessors because the model developed in the previous section is a process instead of a resource. Special attention has been paid to the person's ability to select the appropriate response "plan." This ability to select a response plan has been given as much weight as (or more than) the person's actual skill at conducting that plan.

There are therefore two major specific tasks in developing a performance assessment battery in this section. The first is to select a reasonably large number of test procedures that are likely to probe various dimensions of the model. Since many such procedures already exist, this selection is largely a literature exercise. It does not require any new test development, nor does it produce a definitive list, since the procedures represent only a "candidate" set of tests.

The second task is more creative. It involves the design of a procedure by which the test array determined previously will be subjected to criterion-based validation using nonlinear procedures. To the authors' knowledge, this task represents the first attempt to define how such procedures might be applied for such a purpose. In the present case, this task involves describing how the test battery might be validated against a criterion of "selection accuracy," that is, how well can it select successful performers in various tasks? The road map for conducting such an application is described in the following paragraphs.

#### The Test Battery

A first generation set of tests designed to probe those characteristics considered to be critical to the performance model has been selected by NTI, Inc., under the present contract and based on previous work. It represents a first approximation of the kinds of assessment instruments that are likely to be sensitive at very high levels of functioning. The testing procedure is, of course, not fully specified at this point but should be clear in general

outline from the discussion that follows. The tests included in the battery are listed in Table 1 and described briefly in Appendix C.

#### Validation of the Test Battery

A classical paradigm for validating a series of candidate tests for selection purposes involves giving the tests to samples of subjects who are already clearly differentiated on the criterion task (e.g., rated "outstanding" and "marginal") or giving it to groups of trainees. In either case, the ability of each test to predict the criterion is determined. Typically, the best tests are then combined in some type of linear weighting technique so that the total battery accounts for as much variance as possible. The basic experimental aspects of the approach described herein do not differ from the classical paradigm. The data to be collected consist of the array of scores on the test battery described previously.

Table 1

#### Tests Recommended for the Performance Assessment Battery

---

##### INTERNAL STATE (ENERGETIC) MEASURES

1. Epoch analysis of the electroencephalogram (EEG)
2. Galvanic skin response
3. Eye blink patterns
4. Voice stress analysis
5. EEG spatio-temporal mapping
6. Personality measures

##### ATTENTION ALLOCATION MEASURES

7. Combined tracking and spatial orientation
8. Complex coordination
9. Time sharing (divided attention)
10. Perceptual speed
11. Dichotic listening
12. Directed attention (three levels of difficulty)

##### INTUITIVE PROCESSING DOMAIN MEASURES

13. Backward masking
14. The psychological refractory period
15. Two-flash threshold
16. Critical flicker fusion (CFF)
17. Steady state visually evoked response
18. Auditory brain stem evoked response (BSR)

##### REFLECTIVE PROCESSING DOMAIN MEASURES

19. Semantic reasoning
  20. Mental rotation
  21. Item recognition and immediate or delayed memory
  22. Short-term memory or retrieval (Sternberg)
  23. Semantic memory (Posner)
  24. Simple tracking
-

The novel aspect of the present approach involves the treatment of the scores. Instead of an algorithmic, reductionistic treatment, all test scores serve as input to (at least) a back-propagation neural network, using the criterion classification as the prediction goal. (The reasonably familiar and well-understood back-propagation net has been selected as the most likely to yield an efficient result. However, if this approach proves unwieldy, other neural net approaches can be tried.) This treatment subjects the scores to massive parallel processing, both in a computational sense and in the sense that the interactive results of all tests are considered. Thus, the processing is compatible with the nature of the model proposed.

In more familiar and somewhat superficial terms, the procedure iteratively "tests" different combinations of interactive effects among every test in the battery. For each combination, the "success" of the final output in matching the criterion measure is determined. Combinations that yield high prediction continue to be modified until an optimum prediction is achieved. In this sense, the net "learns" which interactive combinations of test scores produce the best prediction. To our knowledge, this neural net approach has only been used in one other testing context. Kabrisky, at the Air Force Institute of Technology, used input from several physiological measures to develop a neural net solution to predict motion sickness (personal communication). The resulting solution was not intuitive but provided better prediction than a linear weighting system.

Obviously, the actual process is not always that simple. There may be no pattern in the test scores, in which case, the net will never produce a usable result. In addition, since the computational power required and the time necessary for the net to learn can each become prohibitive when many variables are involved, it may be necessary to make some simple assumptions in actual practice. This simplification has been done in the applications described as follows. However, recent developments in neural net technology have mitigated these problems somewhat. For instance, if the data can be structured correctly, it is now possible to perform certain neural net processes, which used to take days, in a matter of minutes. Thus, it is felt that application of these powerful pattern recognition techniques to the complex questions of selection and training is now feasible. Application of these techniques might be accomplished as outlined in the following paragraphs.

#### Application to Soldier Selection

As noted in the introduction, military tasks increasingly require higher cognitive abilities, higher work loads, and more efficient responses. A key concern is the selection of people who can perform well in that environment or at least have a capacity to learn to perform well. In this respect, one is looking for skills or "traits" that are conducive to such performance. Thus, test batteries and selection criteria must be directed to relatively enduring characteristics that predict good performance.

In view of this, a selection battery based on the present approach uses scores from the individual tests, which are obtained after a standard period of practice of each test. In the test development phase, subjects representing clearly differentiated skill levels of particular jobs are trained about the tests, and their plateau level of performance is used as the "score" for that test. These scores are then fed to the neural net, and the net is allowed to learn the optimal test result combination that predicts membership in the criterion group. It is important to remember that this

"solution" may not be absolutely specified; it may include a range of possible combinations of test scores. In any case, from the results of this exercise, it will be possible to select, from the candidate battery proposed, those test procedures that contribute to the final prediction and to combine them into a second generation battery (presumably much smaller and tailored to be more practical for field use). Traditional experimental and psychometric techniques for cross-validation could then be applied to fine tune the final selection battery.

The ultimate outcome of this approach differs from traditional test development outcomes in several ways, although it essentially uses many of the same techniques. First, the "selection criterion" for each job category is not fixed but may contain a number of different combinations of test scores, which predict success in the job equally well. Secondly, it would be expected that, to the extent that the underlying model of performance is general, a single set of tests would serve as a selection device for many tasks, because different neural net solutions would be expected to predict different criterion outcomes. Thus, the ultimate output of such a battery might actually be couched in terms of "success probability" in each of many different tasks. There would no longer be specific skill tests (e.g., mechanical aptitude, or even "pilot selection"). Rather, one general test would reveal particular combinations of scores that predicted success in actual tasks.

A final difference between this approach and traditional test batteries stems from its dynamic nature as opposed to static, algorithmic testing. Because of this feature, the approach would be expected to be more applicable to predicting which people would display more capacity in processes rather than in simple skills. For instance, the question of "work load capacity" in a person refers to a dynamic process (sometimes called an emergent construct) which spans many activities. Such constructs appear, on the surface, to defy prediction unless tied to very specific tasks. It is difficult to imagine how traditional testing could predict a person's work load tolerance in general, that is, separate it from the task in which work load was varied. However, since the model and the testing procedure described here are general and inter-active, there is a much greater chance that they will be able to probe the actual dynamic mechanisms underlying such complex constructs. As long as valid criterion groups can be defined (e.g., people who really do have excellent work load capacity), there is no reason to suppose that the proposed tests, supported by the model, will not uncover these mechanisms. Thus, use of the battery to select people with high degrees of work load capacity, situation awareness capacity, decisiveness, or other such complex performance capabilities becomes theoretically feasible.

#### TRAINING TECHNOLOGIES RELATED TO THE MODEL

Just as the performance model suggested specific approaches for selection testing, it also suggests specific training approaches. In particular, it suggests that the "amount of individual skills" that a person possesses is only a part of the overall story of human performance (although this is obviously important). Rather, the model suggests that the process of how these skills interact with each other will account for the greatest variance in individual performance. Thus, the training concepts that evolve from the present model are directed primarily to those aspects that have not been adequately addressed before. Obviously, no one is suggesting that specific skills or job knowledge will not have to be learned. Rather, the present model suggests that a considerable improvement in performance might be

achieved (especially in highly cognitive and/or high work load situations) by training the person to optimize processing earlier in the sequence or at an "unconscious" level. This suggestion means that the greatest attention must be directed to the energetic, attention allocation, and intuitive processes. Thus, the following discussion of training concepts primarily concerns such processes and their training. This emphasis is based on the premise that the training concepts presented can be combined with more traditional training to produce an integrated training program.

This section is divided into two major subsections. The first tries to present a novel approach to determining which processes might be deficient in the individual soldier. This subsection is a diagnostic and prescriptive phase, which defines the areas in which the soldier might need enhancement to perform a given task in an optimal way. The second subsection provides rationale and procedures for training the soldier in the various deficient areas. Again, while both the diagnostic and remedial procedures described arise from the general model presented, they are not so specific that the concepts would have to be revised if the model further evolved.

#### A Nonlinear Approach to Diagnosing Performance Deficits

In the section about selection tests, it was pointed out that the goal was to probe enduring traits of the person--those things that are not easily changed. In performance assessment, one is more interested in "shorter term" capabilities. These capabilities are shorter term only in the sense that they represent the way that the person is doing the task now; they could be changed through training. In effect, the goal is to define how the people are doing now, rather than to predict whether they will perform well in the future. To be most productive, such testing should not only give an overall assessment of the person's level of performance but should indicate "weak" areas that could be improved by training.

The model presented in the section entitled "A Model of Complex Performance" proposes that final performance is the product of an interdependent series of processes, which energize, select, and employ skills. Failure or deficiency in a task can result from a basic lack of skill or an inadequacy or inappropriate relationship among the various processing stages. Nonlinear techniques can be used in a two-stage process to achieve these goals. In the first stage, neural net techniques are used to define the set of optimal combinations for a given task. Defining optimal combinations for given tasks is accomplished for each task separately by having persons of various skill levels perform the actual task, a simulation, or a synthetic work task. Simultaneously, a range of dependent measures would be collected from the task itself. These measures would be selected to probe each of the dimensions of the performance model. In other words, people with a range of performance capabilities in a specific task are tested, and the pattern of "scores" from a variety of measures related to optimum performance is defined.

Definition of this optimal pattern is done through the same neural net approach described in the section entitled "A Candidate Performance Assessment Battery and Its Nonlinear Validation" for selection testing. The dependent measures are fed into the net, using the criterion of the person's overall performance of the task, simulation, or part task. The net determines the optimum combination of these measures for skilled performance, performance during high work load, or any other performance criterion. In this way, "appropriate" or optimal levels and combinations of skills and processes are defined, which can serve as "targets" for good performance in each task.

The second stage uses the same set of dependent measures for each person and determines the person's specific pattern of performance. The goal then is to compare the person's pattern against the "optimal" pattern(s) determined in the first stage. The exact technique by which this comparison can be performed has not yet been developed but should not represent too much of a challenge. In any case, the result will be a description of the discrepancy between how a person is trying to perform the task now and an optimal way to perform it. This description provides the prescriptive guidelines for the person's training needs. It also sets the targets for the next remedial activity.

## Training Approaches

In this section, it is suggested that certain training approaches that are not commonly used become more critical in the present model. Most notably, techniques that focus on early processing stages are emphasized. In addition, the nonlinear techniques described earlier suggest ways in which on-line assessment can be incorporated into a total training system. These two major areas are discussed in the following paragraphs.

For at least two reasons, traditional approaches to training would not satisfy the prescriptive criteria established for each person. First, they are too rigid and deterministic. The new prescriptive guidelines will not specify that the person must achieve a certain "score" on a certain "test" to meet the criteria. Rather, the guidelines will match the person's overall style and levels of performance against several complex criteria. In other words, there will probably be several ways a person can reach the point of optimal performance. New training and evaluation techniques must be developed to accommodate this much more complex set of remedial goals.

A second deficiency of current techniques is emphasis. Most skill training focuses on "reflective" processes, but little attention has been given to general ways to train the "intuitive" processing domains. Similarly, little attention has been paid to evaluating "internal states" (e.g., the energetic dimension) of the operator as a determinant of performance quality. In the following discussion, these two aspects of new training approaches are emphasized: the need for techniques to learn intuitive processes and the need for an integrated nonlinear training and testing approach.

## Techniques for Training Intuitive Processes

Specific instructional techniques devoted to intuitive processes have been developed extensively (Secrist & Hartman, 1993), and the following sections rely heavily on these formulations. The essential concept of these techniques is that the central nervous system must be driven to respond to increasingly challenging and urgent situation assessment and decision requirements and it is capable of significantly increasing its capacity to respond to such situations. The training techniques use rapid fire presentations of highly realistic task and mission situations, along with exacting control of visual access time and decision or response time. The synthesis of specialized training methods with authentic task content is executed within an adaptive operative paradigm that shapes performance by reinforcement (positive feedback). An integral part of this approach is to match the training challenge to trainee skill level, performance, and transient internal states.

The principal objective of the present training approach is to maximize the accuracy and speed of decision making during stressful, urgent conditions. The concept of optimizing decision speed and accuracy through speed-forcing functions is central to this approach. Five major aspects of the methodology are described in this section: speed-accuracy optimization, speed-forcing functions, pattern masking, automated processing, and skilled memory or content authenticity. Obviously, these five aspects represent only a small sample of the overall training approaches suggested by the response domains and processes in the overall model. However, they suggest the nature of such approaches.

### 1. Speed-Accuracy Optimization (SAO)

Conventional wisdom regarding human performance recognizes that people are seldom able to maximize speed and accuracy in any given situation. Speed-accuracy trade-offs in performance typically result from a conscious decision to emphasize either speed or accuracy. A major premise of the present methodology is that both speed and accuracy can be optimized to the limits of individual capability (e.g., SAO instead of speed-accuracy trade-off [SATO]), provided that cognitive and situational ambiguity are removed from the training situation and task demands for speed are consistent. Accordingly, in the present training methods, accuracy and speed criteria are explicitly defined, and feedback is provided about the speed and accuracy of performance.

In addition to this control, an adaptive linkage between speed and accuracy provides a consistent contingency yoke, which ensures that speed requirements change only as a predictable function of performance accuracy. In other words, speed is regulated by the training system and increases or decreases in a consistent way in response to stable changes in performance accuracy.

### 2. Speed-Forcing Functions

The pivotal aspect of the present training methodology is a set of speed-forcing functions, which are specifically tied to different processing stages. In effect, the times permitted for information acquisition, processing, decision, and response are separately controlled, and the subject can be "driven" to maintain performance in the face of increasing time demands in one or more of these functions. Once performance is stabilized at the criterion, the temporal duration step function proceeds to the next level. The functions are designed to drive the relevant perceptual-cognitive processes to greater resolving power by incrementally reducing the time available for applying mental operations to the stimulus content.

This process enables training to drive visual access, decision, and response time to an absolute minimum, limited only by a person's innate potential. Optimally, in practice, the speed-forcing functions are applied to the mental operations performed on highly authentic task content, while the trainee attempts to achieve mission and task objectives. This process is aimed at enhancing task-relevant skilled memory and simultaneously reducing the temporal parameters of the major information acquisition and processing events. The speed-forcing functions control visual access time over a series of temporal gradients ranging from 2000 ms to 17 ms. Processing, decision, and response times are regulated between 2000 ms and 100 ms by corresponding speed-forcing functions. These functions are applied within the context of other task difficulty parameters concerned with stimulus

array discrimination complexity, task diagnosis demands, and decision requirements.

### 3. Pattern Masking

Pattern-masking techniques are used to achieve exacting millisecond control over visual access time. Pattern masking, a form of backward masking, involves the application of a pattern mask immediately following stimulus onset to terminate the orderly acquisition and processing of the stimulus information. The pattern or contour information contained in the masking stimulus interrupts the processing of the original stimulus. The time interval between onset of the target stimulus and the onset of the pattern mask is known as stimulus onset asynchrony (SOA).

Pattern masking makes it possible to present and regulate a variety of stimulus arrays over a wide range of intensities and durations, including stimulus intensities and durations in the region between neurophysiological awareness and conscious awareness. Moreover, pattern masking is not only instrumental in attaining precise control of visual stimulus accessibility but also addresses the matter of individual differences quite well because masking operates on central or cognitive processes that are susceptible to training and experience (Turvey, 1973). Pattern masking also yields valuable insight about the time course and nature of perceptual-cognitive processing as revealed by varying the time of mask onset (SOA) in relation to a particular cue or stimulus array and examining the consequences along a millisecond time line. Even extremely brief SOAs permit the acquisition and processing of certain semantic cues and physical characteristics, a situation that holds when the brevity of the SOA time interval is reduced to the point that conscious awareness is precluded.

The capacity of the pattern-masking technique to precisely regulate visual access time is a valuable methodological asset in this training. Pattern masking can be used to adaptively modulate the time available for information acquisition within an operant paradigm. Thus, the task challenge governing information acquisition can be maintained at the leading edge of performance. Pattern masking is an important training capability as some urgent task requirements compress the information acquisition and processing time to the point that only milliseconds are available to reach an effective decision.

### 4. Automated Processing Methods

These training methods are also intended to foster automatic processing by establishing and reinforcing consistent mapping between the stimulus patterns and appropriate motor response programs, since extensive automatic response characterizes most highly skilled performance behaviors. The stimulus content employed in this training is consistently linked to an optimal response repertoire through urgent, operant shaping procedures and positive feedback. The consistency of these relationships, in combination with a large number of training trials or cycles and intensive rapid fire stimulus presentation methods, supports the development of automated responses. Rapid fire repetition of determinant cues and critical stimulus patterns sharpens discrimination and aids in the development of automated cognitive processing. Establishing the key linkages between stimulus content and automated response programs involves repeated execution of a series of critical training tasks that collectively require the finely tuned integration of all the primary intuitive skills.

## 5. Skilled Memory and Content Authenticity

Authentic task content is crucial to the development of skilled memory. Skilled memory refers to the magnitude and availability of knowledge possessed by experts. Extremely rapid (nearly instantaneous) storage and retrieval are essential to make an expert's knowledge immediately useful. Skilled memory possesses many of the functional characteristics of short-term memory (working memory) but with vastly larger information content. It is the authors' thesis that to maximize the transfer of intuitive skills to the stressful and urgent conditions of the actual operational environment, skilled memory must be developed about task content that is authentic with respect to the perceptual and cognitive components of the actual operational missions and tasks.

Authentic task content therefore ensures maximum transfer of training to actual mission situations. Training to acquire near threshold information, establish automated processing, and reduce decision time demands congruency between training content and actual operational task content, at least with respect to the perceptual and cognitive aspects of the task. As noted in the performance model described in the section entitled "A Model of Complex Performance," it appears that skilled long-term memory can be developed to the point that extremely fast storage and retrieval rates can be achieved without recourse to short-term memory. As a result, highly developed skilled memory capabilities can be expected to dramatically reduce information search time, decision time, and interfering knowledge states. This reduction obviously will impact the person's capacity for higher cognitive work loads. As training progresses, information encoding and retrieval processes become faster and more reliable, and the connections between the perceived cues or distinctive features in the stimulus field and the internal memory representations are strengthened.

### Need for Re-training

An advantage of this approach is that it focuses on the development of automated skills, which, once learned, appear to require little retraining. The classic statement that once one learns to ride a bicycle, the skill is never lost, is appropriate here. It is hypothesized that in this training, neural circuitry is permanently modified so that, even after a long period of disuse, it can be rapidly reactivated. In practical terms, once the skills are developed through this training (especially the HP-I, attention allocation, and energetic skills), they do not have to be systematically relearned. After a long period of disuse, a few repetitions of the required task would be expected to reactivate the neural circuitry. Thus, no complicated criteria for retraining need be formulated. A simple time-away-from-task criterion might be employed, and an extremely short refresher training regimen might be developed. Of course, the precise definition of these criteria and regimens should be determined experimentally. In addition, the HP-II skills involved (as well as the actual task content) may require additional training. However, again, the existence of the model should facilitate the development of optimal training schedules even for these very specific skills.

### On-line Nonlinear Testing During Training

Some aspects of the training approaches described previously have been incorporated into a "situational awareness training system" (SATS), which is being used experimentally by the U.S. Air Force. This system provides the necessary timing and stimulus generation techniques to conduct training of

both intuitive and reflective functions. However, it provides for relatively traditional measurement of operator performance, in terms of terminal reaction time and percent correct scores. As such, it is not using the power of the nonlinear approaches described here. The way in which such approaches could be integrated into the training system is presented in this section.

The power of the model presented earlier, used in conjunction with the nonlinear approach, is that specific functions can be tested, and the full complexity of their interactions with each other can be used as a dependent measure. In other words, two testing results are obtained simultaneously. First, the model allows one to identify specific information processing and response activities that can be probed by specific scores. This concept is not particularly novel. However, the nonlinear approach also allows the processes that occur as a result of complex interdependencies among these specific activities to be evaluated; this concept is novel.

Based on this view, it is logical that any training system would include a neural net capability, which would take selected variables from the performing subject and evaluate the person's performance on line against the pre-established criteria. This capability would then fully employ the techniques described previously for individual performance assessment to (a) evaluate the student's progress in the processes targeted for improvement, and (b) assess overall progress so that students could be free to develop different patterns of performance, which might lead to optimal performance for that person.

Obviously, the detailed customization of these concepts to actual Army tasks is a complex undertaking. However, a generalized example of how this customization could be done in the context of command and control (C<sup>2</sup>) training is presented in Appendix D, which illustrates how the demands of the actual Army task can be interpreted in terms of the performance model and presents general guidelines for developing a training system from this analysis. Again, while generic, this illustration should suggest how various Army skills could be enhanced through such innovative training.

## SUMMARY AND RECOMMENDATIONS

A model of human performance has been proposed, which, while borrowing from many previous models, represents a unique synthesis of current directions. Most notably, this model proposes that cognitive processing activities are performed in parallel and probabilistically. At each stage of the processing sequence, probabilistic weights are assigned to various stimulus characteristics, and these weights influence activity at the next processing stage. This conceptualization sets the stage for viewing human performance as a "non-algorithmic" phenomenon and suggests that nonlinear analysis techniques should be employed in its analysis.

Therefore, two specific applications of these techniques were described in general terms. These applications involve the development of selection tests and new training techniques. Both applications were conceptualized in terms of test results or performance measures that served as inputs to a neural network. By choosing the appropriate criterion, the neural net can learn to discriminate the pattern of scores that predicts optimal performance, deficiencies in a person, or achievement of criterion performance by a person. Since these patterns are related to the performance model, training techniques targeted to a person's deficiencies can be employed, and a sample of these techniques was described.

This report has established the theoretical feasibility of the concepts presented. However, it is recognized that this novel approach will require considerable experimental and theoretical work before it can be considered for operational use. As a minimum, the following recommendations detail the steps necessary to validate, extend, and tailor these concepts so that they may ultimately be introduced operationally and may enhance soldier performance.

1. The model of performance must be subjected to considerable peer review for elaboration and revision. Although based on sound theoretical principles, it tries to encompass many diverse areas, some of which are quite controversial. Therefore, although the overall model might retain its general structure, there is ample opportunity for specific modifications. This development is not required before subsequent steps can be taken, however.

2. Mathematical specification of the nonlinear alternatives open to these applications must be made. These alternatives represent a rapidly moving field in mathematics, and it would be desirable that the state of the art be defined precisely before any particular nonlinear technique is selected.

3. A breadboard version (an experimental setup to test feasibility) of the candidate test battery should be developed, standardized, and employed in a series of brief criterion-based pilot studies to establish each test's applicability to the processing stage it is hypothesized to measure.

4. A demonstration or proof-of-concept study should be conducted to use the nonlinear approach in generating a specific selection test for at least one Army task. This study should use appropriate classical psychometric techniques to establish the feasibility of the approaches recommended in this report and should result in at least a preliminary selection battery for the task tested.

5. A training device should be built, which incorporates the techniques recommended for training intuitive and reflective processes. This device should also include the nonlinear assessment techniques recommended for performing on-line evaluation of a person against an optimal set of criteria. In the interest of efficiency, the Army task selected for this training should be the same as that studied in Recommendation 4.

## REFERENCES

- Analytical Assessments Corporation (1988). Final progress report: The effects of pre-treatment drugs on military performance. Alexandria, VA: System Research Laboratory, U. S. Army Research Institute.
- Anderson, J.R. (1990). Cognitive Psychology and Its Implications. New York, NY: W. H. Freeman & Co.
- Baddeley, A.D., & Liberman, K. (1980). Spatial working memory. In R. S. Nickerson (Ed.), Attention and Performance VIII. Hillsdale, NJ: Erlbaum.
- Best, J.B. (1986). Cognitive Psychology. St. Paul, MN: West Publishing Company.
- Bonds, R. (Ed.). (1987). The modern U.S. war machine: An encyclopedia of American military equipment and strategy. New York, NY: Crown Publishers.
- Carretta, T.R. (1989). USAF pilot selection and classification systems. Aviation, Space and Environmental Medicine, 60 (1), 46-49.
- Chase, W.G., & Ericson, K.A. (1980). Skilled memory (Technical Report No. 5). Pittsburgh, PA: Carnegie-Mellon University. (AD-A114 635).
- Colley, A.M., & Beech, J.R. (Eds.) (1989). Acquisition and Performance of Cognitive Skills. New York, NY: John Wiley and Sons.
- De Greene, K.B. (1990). Contextual aspects of human factors: The case for a paradigm shift. Human Factors Society Bulletin, 33(9), 1-3.
- Dixon, N.F. (1981). Preconscious processing. New York, NY: John Wiley and Sons.
- Dunnigan, J.F. (1988). How to make war (rev. ed.). New York, NY: Quill.
- Easterbrook, J.A. (1959). The effect of emotion on cue utilization and the organization of behavior. Psychological Review, 66, 187-201.
- Foss, C.F. (Ed.). (1989). Jane's armour and artillery 1989-1990. New York, NY: Jane's Information Group.
- Gardner, H. (1987). The mind's new science. A history of the cognitive revolution. New York, NY: Basic Books.
- Gopher, D., & Donchin, E. (1986). Work load--An Examination of the Concept. In Boff, K. R., Kaufman, L. and Thomas, J. P. (Eds.). Handbook of Perception and Human Performance Vol II. New York, NY: John Wiley and Sons.
- Green, D.M., & Swets, J. A. (1966). Signal detection theory and psychophysics. New York, NY: John Wiley and Sons.
- Grunwald, H.A. (Ed.) (1986). Artificial intelligence: Understanding computers. Alexandria, VA: Time-Life Books.

- Halberstadt, H. (1989). NTC: A primer of modern land combat. Novato, CA: Presidio Press.
- Hassig, L. (Ed.). (1990). The armored fist. Alexandria, VA: Time-Life Books.
- Hedgepeth, W.O. (March, 1993). The science of complexity for military operations research. Phalanx: The Bulletin of Military Operations Research, Military Operations Research Society, 101 S. Whiting St., Alexandria, VA 22304-3483, 26(1), 25-26.
- Hockey, G.R.J. (1986). Changes in operator efficiency as a function of environmental stress, fatigue, and circadian rhythms. In Boff, K. R., Kaufman, L., and Thomas, J. P. (Eds.) Handbook of Perception and Human Performance (Vol. II). New York: Wiley.
- Hockey, G.R., Gaillard, A.W.K., & Coles, G.H. (1986). Energetics and human information processing. Dordrecht, Netherlands: Martinus Nijhoff.
- Humphries, M.C., & Revelle, W. (1984). Personality, motivation, and performance. A theory of the relationship between individual differences and information processing. Psychological Review, 91, 153-184.
- Jex, H.R., McDonnell, J.D., & Phatak, A.V. (1966). A "critical" tracking task for man-machine research related to operator's effective delay time. Proceedings of the second annual NASA University Conference on Manual Control. (Report No. NASA-SP-128). Cambridge, MA: Massachusetts Institute of Technology, 361-377.
- Matlin, M. (1989). Cognition. New York, NY: Holt, Rinehart and Winston, Inc.
- McLeod, P., & Posner, M.I. (1985). Privileged loops from percept to act. In H. Bouma & D. G. Bouwhuis (Eds.), Attention and Performance X: Control of Language Processes. London: Erlbaum.
- Meister, D., (1991). The definition and measurement of systems. Human Factors Society Bulletin, 34(2), 3-5.
- Miller, D., & Foss, C. F. (1987). Modern land combat. New York, NY: Crown Publishers.
- Navon, D., & Gopher, D. (1979). On the economy of the human-processing system. Psychological Review, 86, No. 3, 214-255.
- O'Donnell, R.D. (1990a). Evaluation of the man-machine interaction in advanced aircraft systems. Paper presented at the 1990 Paris Air Show.
- O'Donnell, R.D. (1990b). Modeling, assessment, and enhancement of cognitive performance (USAFSAM-TP-90-6). Brooks Air Force Base, TX: U.S. Air Force School of Aerospace Medicine.
- O'Donnell, R.D. (1991a). Directions in performance assessment: Results of the workshop on future metrics and models for assessment of human/system performance in advanced military systems. CSERIAC, Det. 1, AL/HE/CSERIAC, Wright-Patterson AFB, Ohio 45433-6573.

- O'Donnell, R.D. (1991b). Recommendation for an internal states module to interface with the situational awareness training system (SATS) (Final report). Dayton, OH: NTI, Incorporated.
- O'Donnell, R.D., & Eggemeier, F.T. (1986). Work load assessment methodology. In Boff, K. R., Kaufman, L. and Thomas, J. P. (Eds.) Handbook of Perception and Human Performance Vol II. New York, NY: John Wiley and Sons.
- Posner, M. (1978). Chronometric exploration of mind. Hillsdale, NJ: Erlbaum.
- Rhodes, J.P. (1989, December). All together at Fort Irwin. Air Force Magazine, pp. 38-45.
- Rigg, K.E., Harden, J.T., & McFann, H.H. (1985). List of missions/tasks/subtasks, complex cognitive abilities, and complex cognitive repertoires for command and control function (Technical report). Monterey, CA: McFann, Gray, and Associates, Inc.
- Romjue, J.L. (1984, May-June). The evolution of the AirLand Battle concept. Air University Review, pp. 4-15.
- Sanders, A.F. (1983). Towards a model of stress and human performance. Acta Psychologica, 53, 61-69.
- Secrist, G.E. (1988). Situational awareness training system. Phase II SBIR Proposal, Topic AF 87-080. Proprietary document used with permission.
- Secrist, G.E. (1990). Situational awareness training: A feasibility demonstration. (USAFSAM Technical Report, in press). Brooks AFB, TX: U.S. Air Force School of Aerospace Medicine.
- Secrist, G.E., & Hartman, B.O. (1993). States of awareness I: Subliminal perception relationships to situational awareness (AL-TR-1992-0085). Brooks Air Force Base, TX: Armstrong Laboratory.
- Shastri, L., & Feldman, J.A. (1986). Neural Nets, Routines, and Semantic Networks. In Advances in Cognitive Science 1, Sharkey, N. E., Ed. Ellis Horwood Limited, Chichester, West Sussex, England, pp. 158-203.
- Sheridan, T.B. (1991). New realities of human factors. Human Factors Society Bulletin, 34(2), 1-3.
- Shingledecker, C.A., Crabtree, M.S., & Acton, W.H. (1982). Standardized tests for the evaluation and classification of work load metrics. Proceedings of the Human Factors Society Annual Meeting, 648-651.
- Skinner, M. (1989). USAREUR: The United States Army in Europe. Novato, CA: Presidio Press.
- Smolensky, P. (1986). Formal modeling of sub-symbolic processes: An introduction to harmony theory. In Advances in Cognitive Science 1, N. E. Sharkey, Ed. Chichester, West Sussex, England: Ellis Horwood Limited, pp. 240-235.
- Solso, R.L. (1979). Cognitive Psychology. New York, NY: Harcourt Brace Jovanovich, Inc.

- Sternberg, S. (1969). The discovery of processing stages: Extension of Donder's method. In Koster, W. G. (Ed.) Attention and Performance 2. North-Holland, Amsterdam.
- Turvey, M.T. (1973). On peripheral and central processes in vision: Inference from an information-processing analysis of masking with patterned stimuli. Psychological Review, 80, 1-52.
- Vought, D.B., & Vasile, D.C. (1987). The United States Army. In Bonds R. (Ed.), The modern U.S. war machine: An encyclopedia of American military equipment and strategy. New York, NY: Crown Publishers.
- Warden, J.A. (1989). The air campaign: Planning for combat. New York, NY: Pergamon-Brassey.
- Welford, A.T. (1952). The 'psychological refractory period' and the timing of high-speed performance--a review and a theory. British Journal of Psychology, 43, 2-19.
- Welford, A.T. (1968). Fundamentals of Skill. London: Methuen.
- Wickens, C.D. (1980). The structure of processing resources. In R. Nickerson & R. Pew (Eds.), Attention and Performance VIII. Hillsdale, NJ: Erlbaum.
- Wickens, C.D. (1981). Processing resources in attention, dual task performance, and work load assessment. (Technical Report EPL-81-3/ONR-81-3) Engineering-Psychology Research Laboratory, University of Illinois.
- Wickens, C.D. (1984a). Engineering Psychology. Columbus, OH: Merrill.
- Wickens, C.D. (1984b). Processing resources in attention. In Varieties of Attention, Academic Press, pp. 63-102.
- Yerkes, R.M., & Dodson, J.D. (1908). The relation of strength of stimulus to rapidity of habit-formation. Journal of Comparative and Neurological Psychology, 18, 459-482.

**APPENDIX A**  
**REVIEW OF HUMAN PERFORMANCE THEORIES**

## REVIEW OF HUMAN PERFORMANCE THEORIES

To provide a basis of the performance model presented and used in this report, the history of such modeling efforts is described here. The following review of performance theories ranges from historically significant but currently unpopular theories to new approaches with unknown value. Since many of these approaches evolved from the long literature developed in the context of studying "work load," that construct is frequently mentioned. However, the review focuses on the generic term "performance," since the model to be developed will try to encompass the whole spectrum of complex tasks and emergent performance constructs.

Increasingly, such complexity is being subsumed under the general term cognition. The concept of cognition is now defined as the operator's ability to perceive and effectively handle the demands of the environment (including all the motivational and resource limitations that may be involved). In other words, the critical issue in performance assessment becomes human cognition, and investigations of performance become defined in terms of limitations of the capacity of the human information processing system (Gopher & Donchin, 1986). Further analysis reveals that such limitations typically involve the attention system of the human.

The following historical review presents those efforts considered significant in the development of current thinking toward a description of the process of cognition as it relates to performance. Space and relevance dictate that the presentations of each theory be somewhat superficial. Interesting questions, problems, and potential applications could not be raised in the present context. However, the source literature provided should permit the interested reader to pursue any topic further.

### SINGLE CHANNEL THEORY

The single channel theory of mental processing, also referred to as the single-resource model, bottleneck model, or filter model, was among the first theories proposed to explain why humans selectively attend to certain cues rather than process all sensory cues simultaneously.

#### Limited Capacity

In 1958, Broadbent postulated that the location of the "bottleneck" (or limiting factor that makes performance of two demanding tasks difficult) just preceded perceptual analysis (see Figure A-1). Therefore, he believed, not all information was attended to or conveyed for further analysis. That is, information processing is restricted by channel capacity. Two principal limitations of performance exist, according to this theory: (1) there is only one channel facility through which the information can be received at a given time; and (2) the capacity restricting the quantity of information per given time period has limits (Colley & Beech, 1989).

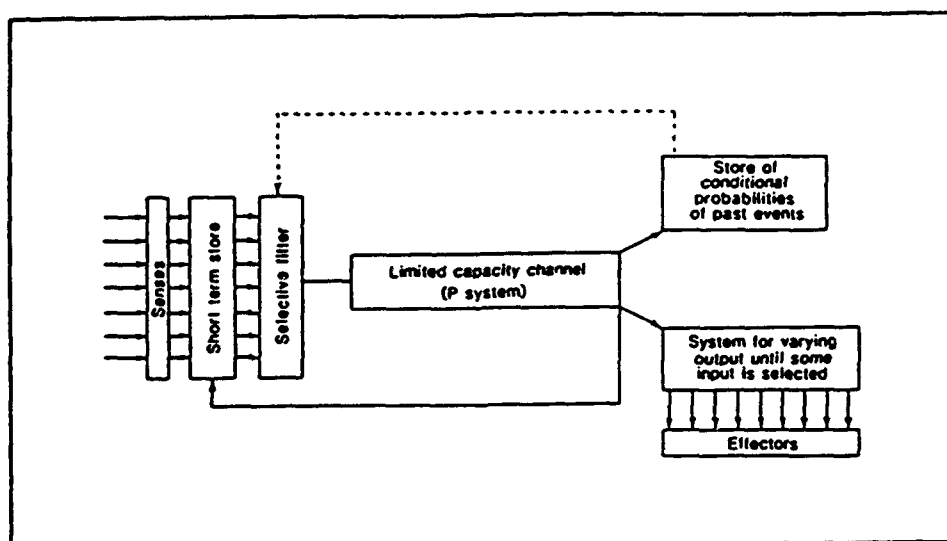


Figure A-1. Broadbent's limited capacity model (from Gopher & Donchin, 1986, p. 41-9, used with permission).

Experiments that tested or demonstrated this theory were done primarily using the psychological refractory period paradigm in which two simple signals were presented in rapid succession. The subject was required to respond as quickly as possible to each signal with a key stroke. The implication was that if the channel were already occupied by a preceding stimulus and a second stimulus arrived, requiring a response, it would have to wait for processing until the decision channel was free. Also, the sooner the second signal followed the first, the longer it was required to wait. The delays occurred even when the subjects used different fingers or keys to respond and when the signals required different inputs (e.g., visual versus auditory) (Colley & Beech, 1989).

Despite support of this theory from such experiments performed throughout the 1950's, an obvious problem was evident from later experiments and common knowledge that some information could be detected through an unattended channel. Several experimenters during the 1970's challenged the single-channel theory, citing galvanic skin response studies in which results suggested that unattended signals were not only detected but also processed, thus damaging Broadbent's filter theory (Solso, 1979). Efforts to reproduce the findings led to work by Treisman, described as follows.

#### Attenuation Model

A modified, if not totally new, model was proposed in 1960 by Treisman (Matlin, 1989), who suggested that an analytical process must occur before the filter. She suggested that portions of a person's store of words contained lower thresholds for activation than others, explaining why one's own name or the cry of one's own child could be more easily activated than less "important" signals. Treisman's model was based on experiments with dichotic listening, or "shadowing" (subjects were given two different sets of information in the left and right ears and asked to only attend to one ear's

message). These experiments suggested that a cerebral "executive" first decided to analyze signal characteristics, and therefore, an initial screening of information had to occur. She proposed that the initial screen evaluates the signal on the basis of the physical properties of the stimuli (e.g., pitch and intensity of auditory stimuli). A second screen evaluates which stimuli are linguistic and groups them into syllables and words. A third and more sophisticated screen then evaluates its meaning. However, all three tests are not necessarily made on each incoming stimulus. Treisman's theory seemed to suggest that one hears irrelevant information with a dull, but not deaf, ear (Solso, 1979).

### Pertinence Model

However, the question of how such an executive decision is made remained unanswered until another alternative was proposed by Deutsch & Deutsch in 1963 and later revised by Norman in 1968 and 1976 (Solso, 1979) (see Figure A-2). This model differed from the attenuation model in that it postulated an earlier "pertinence" evaluation in information processing. It was suggested that this initial analysis consisted of a comparison of all signals against the contents of long-term memory, resulting in the attenuation of some signals and the enhancement of others. This system then conveys the message for further processing but in a modulated form.

This model posed a somewhat uneconomical process, in that all stimuli (including a large number of irrelevant ones) must initially be checked against long-term memory before further processing can occur. However, the process appeared to be required since research results seemed to indicate that some processing must occur before selection. Posner and Snyder, in 1975, and Shallice, in 1972, suggested that early selection might only provide integration activity wherein a limited capacity mechanism inhibits certain information and expedites other information (Solso, 1979).

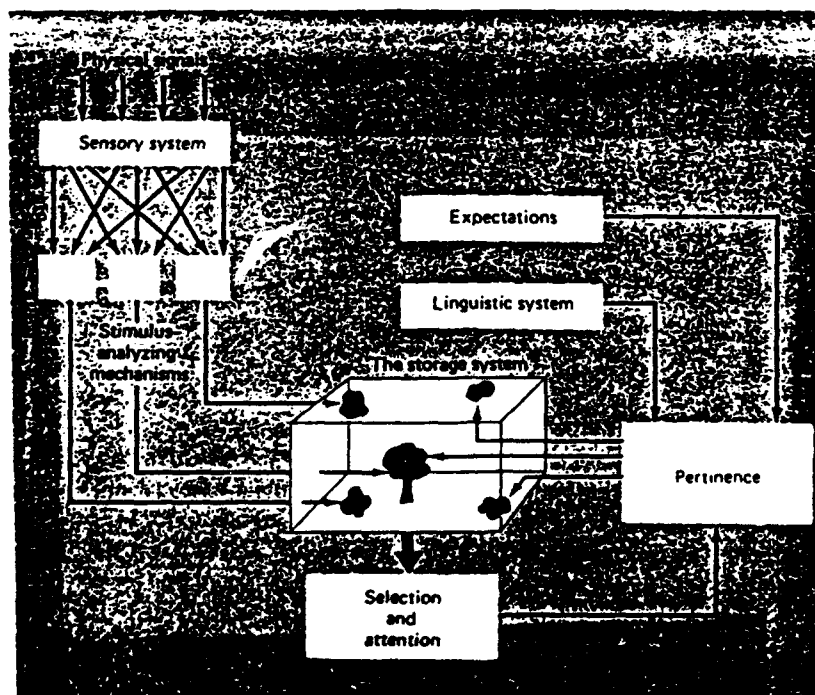


Figure A-2. Pertinence model (Solso, 1979, p. 133, used with permission).

## Capacity Model

Kahneman's efforts in 1970 led him to reconceptualize the bottleneck model by suggesting that it might be more important to understand the amount (capacity) of processing that a task demands of a person, instead of where the bottleneck might be in selective attention (Best, 1986) (see Figure A-3). He viewed the amount of resources available at a given time as limited but varying with levels of arousal. Changes in the "level of arousal and consequent changes in capacity are assumed to be controlled by feedback from the execution of ongoing activities; a rise in these activities causes an increase in the level of arousal, effort, and attention" (Gopher & Donchin, 1986). Part of Kahneman's theory comprised a mechanism responsible for allocation of resources, which is influenced by "dispositions, momentary intentions, and the feedback from ongoing activities."

A significant aspect of this model is that it is energy oriented. It attributes performance decrements to the demands of two concurrent activities exceeding available capacity, regardless of where that capacity may reside in the system. Unlike the structural models proposed, interference between two tasks is seen as nonspecific and dependent only upon the total demands of the two tasks: "a general energy source of a fixed capacity made available to one or another task, but not both" (Gopher & Donchin, 1986).

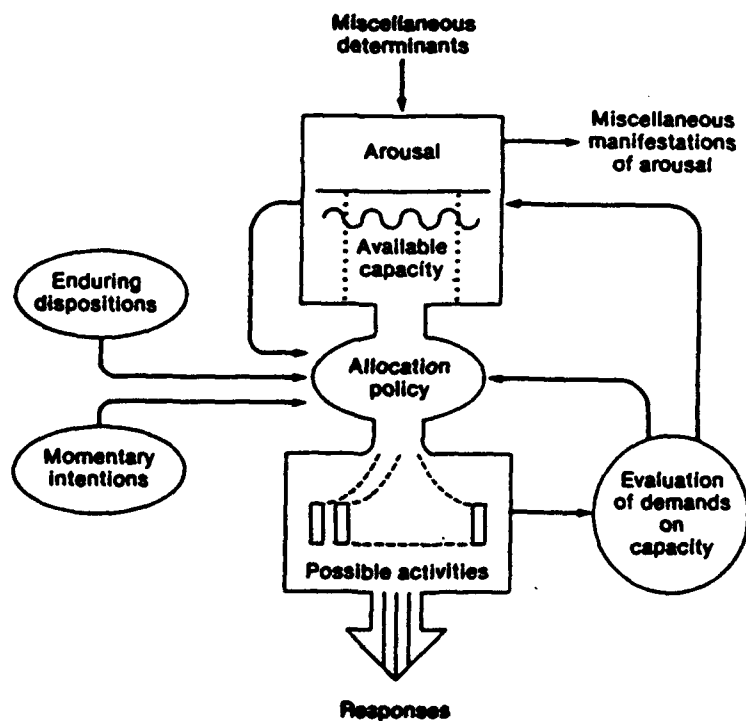


Figure A-3. Capacity theory (Best, 1986, p. 48, used with permission).

This aspect of the resource idea led researchers to try to monitor the level of available resources via the demand on the resources. From this approach stemmed experiments evaluating the effects of effort on physiological responses such as pupil dilation and brain metabolism of gluco-proteins (Gopher & Donchin, 1986; Wickens, 1981). These researchers believed that

performance alone is a poor indicator of resource limitations "because performance is both the result of the limitation and a trigger of a change in the limit via recruitment of additional resources."

The claims of both single-channel and capacity models "that all tasks, regardless of structure, compete with each other, and that an increase in the difficulty of one task will be reflected in the ability to perform another one simultaneously" (Gopher & Donchin, 1986) could not withstand experimental tests. The basic paradigm used in such tests was dual task performance. A key idea in single-channel models, when applied to dual task performance, was that a pool of processing resources was limited in its amount and could be shared by one or more tasks; as more resources are devoted to a task, performance of that task improves, and performance of a concurrent task deteriorates (Colley & Beech, 1989). Data from a variety of experiments showed, conversely, that performance of some pairs of tasks interfered with one type of task yet not with another, or that performance was affected equally when certain tasks or types of tasks were paired. This finding appeared to refute the concept of a "single undifferentiated pool of processing energy."

#### MULTIPLE RESOURCE MODELS

With the apparent rejection of the single-channel theory, a multiple resource model evolved. The idea of multiple resources was invoked to account for various empirical or experimental phenomena in dual task performance (Wickens, 1981). The multiple resource model proposed that the human possesses a number of processing mechanisms, each of which requires its own supply of resources (see Figure A-4). Depending upon the level of arousal (and each resource had a unique dependence upon this level of arousal), a given mechanism will expend a certain amount of energy from its own reservoir. Although there will be continual competition for resources between tasks that require the same resource, there will be no depletion of energy from other, noncompeting resources (Gopher & Donchin, 1986).

Thus, the multiple resource model claims that two activities may occur without mutual impairment and that each can be assigned its own information-processing structure. In fact, a human may even protect performance of one task by recruiting extra resources from a common pool (Colley & Beech, 1989). These authors suggest that one may interpret attention as a mental resource, whose allocation to a mental process is beneficial.

#### The Nature of Multiple Resources

Norman and Bobrow first introduced the term "resources" in 1975, suggesting that the limits of attention occur when several processes compete for the same limited resource (Matlin, 1989). They described data-limited task performance as restricted by memory limitations or the quality of a stimulus and, by contrast, a resource-limited task as one that can be improved by supplying more resources to the task (Matlin, 1989). Norman and Bobrow believed that there is a fixed upper limit of the amount of resources available for processing.

Neisser, in 1976, challenged the then-held assumption that channel capacity limits information, beyond which transmission errors will occur (Gopher & Donchin, 1986). He argued that

While such an argument is valid in principle, it is of dubious relevance to psychology. The brain contains millions of neurons, in unimaginably subtle relationships with one another. Who can say how high the limit imposed by such a "mechanism" may be? No one has ever demonstrated that the facts of selective attention have any relation to the brain's real capacity, if it has one at all. Indeed, no psychological fact has anything to do with the overall size of the brain. Contrary to popular assumption, we have no great cerebral storehouse that is in danger of becoming overcrowded. There are probably no quantitative limits on long-term memory, for example; you can go on meeting new people, acquiring new languages, and exploring new environments as long as your inclinations and energy last. Similarly, there is no physiologically or mathematically established limit on how much information we can pick up at once.

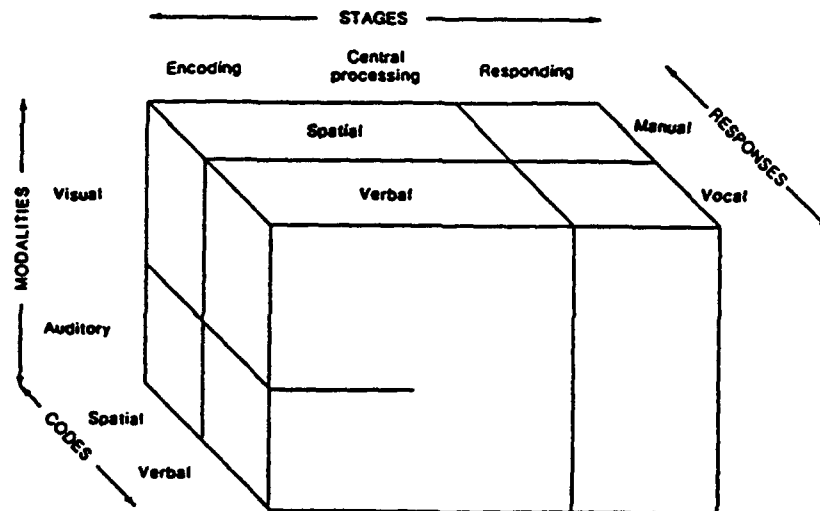


Figure A-4. Wickens' model of multiple resources (from Gopher & Donchin, 1986, p. 41-17, used with permission).

Neisser believed, however, that inefficiency occurs if we try to do several things simultaneously, although with practice, certain pairs of activities can be successfully combined. Neisser argued that perhaps, with practice, we can succeed in attending to two different messages provided through the same channel (e.g., auditory), but if dual listening were really efficient, such attention would have become more common. He believed it more likely that there was a "genuine informational impediment to the parallel development of independent but similar schemata" (Matlin, 1989).

Norman and Bobrow were not specific in describing the nature of resources, of the resources' relationship to one another, or of the demand composition of given tasks. By 1980, researchers began to posit the existence of at least two relatively independent types of resources related to (a) perceptual or computational processes and (b) selection and generation of motor activity (Gopher & Donchin, 1986).

## Resources Structure Model

In the early 1980's, Wickens proposed three parts to the structure of resource reservoirs: stages of processing, cerebral hemispheres, and processing modalities. This model permitted distinctions to be made among verbal and spatial representation codes.

The Wickens model is based on results that suggest that perceptual and central processing resources are functionally separate from response processes. Manipulation of task response difficulty does not affect performance of a concurrent task whose demands are more cognitive or perceptual (or the reverse) (Wickens, 1981; 1984a; 1984b). In addition, processing codes were postulated based on studies that demonstrated that spatial and verbal processes draw upon functionally separate resources and are related in most humans to right or left cerebral hemispheres, respectively. Finally, a distinction was made between visual and auditory modalities in attention. This distinction was based on experimentation that had demonstrated that cross-modal information presentation enhances performance, since it appears easier to divide attention between the eye and ear rather than between two eyes or two ears (Wickens, 1981).

Colley and Beech (1989) note that Wickens himself pointed out some difficulties for his own theory. For instance, Wickens noted in 1984 that one area of research fails to stand within the theoretical frameworks of multiple resource theory--that which involves controlling and coordinating two concurrent motor actions. Multiple resource theory "does not seem to account for an interference effect from physical exertion on a mental activity" (Colley & Beech, 1989). In spite of such potential difficulties, the strength of this model was that it summarized what Wickens believed were the factors that influence the pattern of interference between two tasks being performed concurrently in their competition for access to a central mechanism. However, it did not describe how these structural components relate to one another. In other words, the model lacked motion or energy.

## Cognitive-Energetic-Stage Model

This model evolved from experiments designed to examine the effects of stressors on performance in choice reaction tasks. It constituted a synthesis in that it tried to integrate a structural description of multiple resources with energetic concepts (see Figure A-5). The findings from these studies indicated that certain stressors (fatigue, time to complete, or psychoactive drugs) affected specific mechanisms but had no general effect on task performance (Gopher & Donchin, 1986).

The basic framework of this model was a neurophysiological model of attention control, which was originally developed by Pribram and McGuinness in 1975. This framework proposed three main "energetic generators" of processing activity: arousal, activation, and effort. It suggested that the state of adaptation of the organism to environmental demands determines whether the effort level is in an optimal state and that effort depends upon motivation and situation assessment. The evaluation mechanism is a unique component of this model because it may have a separate influence on different aspects of performance (Gopher & Donchin, 1986).

The concept of the existence of several sources of energetic activity was preliminarily supported by research that distinguished between motor and perceptual resources and appeared to separate tasks along modalities and types

of representation modes (Baddeley & Liberman, 1980; Gopher & Donchin, 1986; Navon & Gopher, 1979; Wickens, 1980).

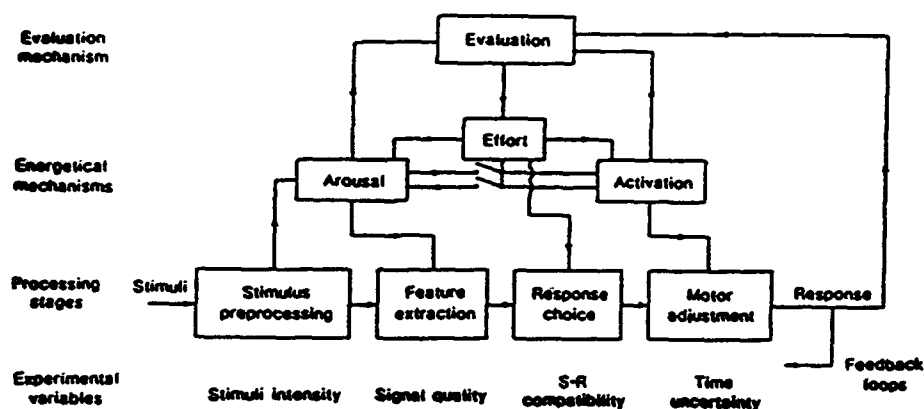


Figure A-5. Cognitive-energetic-stage model of multiple resources (from Gopher & Donchin, 1986, p. 41-18, used with permission).

#### MODEL OF AUTOMATICITY

With respect to performance capacity, however, another issue is pertinent and has gone unmentioned in any of the attention and performance models. This issue concerns the effect of practice on performance and its unique ability to reduce work load. Therefore, another body of theory began to appear, which addresses not just single versus multiple resources but the distinction between automatic versus controlled processing.

Work by Schneider and Shiffrin in 1977 distinguished between two types of processing. Processes can become automatic with sufficient practice. Controlled processing, they believed, requires extensive dependence upon short-term memory and is therefore demanding and slow. Voluntary control is required; it takes little or no training to develop. Automatic processing, on the other hand, is defined as that which, with continued practice, provides an automatic link between stimulus and response and can be operated with minimal input from the central processor (Gopher & Donchin, 1986).

Automaticity is probably best thought of as a matter of degree: highly practiced processes are more apt to be performed with little or no attention at all (Anderson, 1990). Unlike controlled processing, automaticity is not limited by short-term memory, requires minimal processing effort, requires little direct control, but needs consistent and extensive training to develop (Gopher & Donchin, 1986). The concept of consistent mapping has been proposed as the method by which automaticity occurs, according to Schneider & Shiffrin.

The idea of gradually developed automated structures that can be operated as a whole with little investment of processing effort presents an alternate perspective of the structural organization of the processing system.

The underlying metaphor is one of a self-organizing communication network that develops to improve the transmission of information within the system (Gopher & Donchin, 1986, p. 41-19).

Reduced work load thus could occur through automaticity and a reduced need for arousal and activation of the central processor. This occurs because the encoding and response activation aspects of performance gradually become more independent of the energetic and arousal aspects. The net effect of this independence is to free energetic resources for concurrent tasks. Another effect is that while a person may act more like a single processor when training begins, he or she can shift into a multiple resource mode when energetic pools and processing mechanisms gain sufficient independence. The structural dimensions and processing stages emerging from experimental research as significant qualifiers of central processor work may also represent the most natural organizing framework within which automatic segments of behavior or action schema develop (Gopher & Donchin, 1986, p. 41-20).

#### PATTERN RECOGNITION MODELS

Template-matching and feature extraction theories are both types of pattern recognition models. They are used extensively in artificial intelligence as methods that a computer employs to identify objects.

##### Template-Matching Theory

Template-matching theory is a version of pattern-recognition models, according to Best (1986) and Anderson (1990). This approach to information processing basically proposed that incoming stimuli are continually compared against stored codes, or templates, until a good fit is found. This theory has two disadvantages, however: (a) template matching could conceivably be a very lengthy and therefore inefficient method and does not seem to accurately portray how humans perceive and attend; and (b) the system is inflexible, when in fact, human recognition is successful even in view of great input diversity. Because of the difficulties posed by template matching, some theorists proposed that pattern recognition takes place using feature analysis.

##### Feature Integration Theory

In 1980, Treisman and her colleagues revised her earlier views about cognition and proposed the feature-integration model (Best, 1986; Anderson, 1990). This model is similar in construction to the Schneider and Shiffrin automaticity model. The two stages of this model are pre-attentive processing and focused attention. Pre-attentive processing involves the automatic registration of features using parallel processing across the visual field and represents a relatively low level attention roughly similar to Schneider and Shiffrin's concept of automatic processing. Focused attention is more demanding and includes serial processing, which involves identifying objects one at a time, thus being similar to Schneider and Shiffrin's controlled search (Matlin, 1989).

This approach has also been called feature detection theory because its primary assumption was that all complex stimuli are comprised of distinct and separate features. Pattern recognition is thus successfully accomplished by

assessing the presence or absence of features and comparing the result with different labels. This process depends upon stimuli decomposability. A series of steps or stages is required in this model. Features are first extracted and noted, then counted in comparison with the target stimulus. This theory is all or none; either completely accurate or inaccurate information is acknowledged by the human, which helps describe both recognition accuracy and latency (Best, 1986).

This theory also suggested that when attention was maximally stressed or distracted, features could become distorted in perception. This inappropriate combination of features Treisman called "illusory conjunction." Although humans continually fail to devote focused attention to a number of objects in their visual fields, Treisman proposed that the reason they do not experience illusory conjunction more frequently is that top-down processing helps eliminate inappropriate combinations. Top-down screening refers to learned templates that describe in memory store characteristics of objects that are consistent with (learned) expectations, eliminating items that are not within the repertoire of recognizable items (such as green carrots) and encouraging us to see illusory conjunctions that are highly likely (thinking we see the word "day" when "dax" or "kay" is presented) (Matlin, 1989).

#### MATHEMATICAL MODELS

This body of theory evolved from a desire to understand how humans are capable of intelligence and to determine whether computers and their architectures might share this capability (Smolensky, 1986).

#### Harmony Theory

The concept of cognition lends itself to mathematical formalization. The mathematical language used to express this theory emanated from probability theory and the theory of dynamic systems (the study of sets of numerical variables that evolve in time in parallel and interact through different equations, i.e., the study of natural physical systems, such as mathematical physics, or artificially designed systems as in control theory).

Levels of cognitive processing have been defined, the highest being explicit logical reasoning and the lowest, sensory processing (see Figure A-6). Formal logic well describes logical reasoning, and science describes sensory processing, but most cognition occurs between these two extremes and remains unanswered in a satisfactory way. Harmony theory is a top-down strategy which Smolensky (1986) believed addresses the "relatively unexplored conceptual world of parallel, massively distributed systems that perform cognitive tasks."

A symbolic paradigm conceptualizes processing in the intermediate levels as symbol manipulation in a top-down view emulating logical reasoning. A sub-symbolic paradigm, which harmonic theory is, views the intermediate levels of processing as the same kind as sensory-processing mechanisms. The theory's central idea is that properties of a task powerfully constrain mechanisms--similar to the "perceptual approach to cognition where the constraints on the perceptual task are characterized through the constraints operative in the external environment from which the inputs come" (Smolensky, 1986).

Harmony theory embodies a "formal sub-symbolic framework for performing an important class of generalized perceptual computations" (Smolensky, 1986).

This rather complex, 12-point theory can handle information on a higher or lower degree of "harmony"; the mathematical system presumed to be in effect does not stop for "insufficient information...if inconsistent information is given, no available state will have a harmony as high as that of the answer to a well-posed problem... (but) answers derived while violating as few circuit laws as possible will have the highest harmony and...will therefore be selected" (Smolensky, 1986).

Obviously, this description of the harmony theory approach does not capture the richness and complexity of the concepts involved. However, it hints at aspects of cognitive theory that have been barely considered by traditional approaches and are generally consistent with the theoretical framework presented earlier in this report. Further, it suggests several lines of further theoretical and experimental investigation. These concepts formed one important aspect of the overall present project.

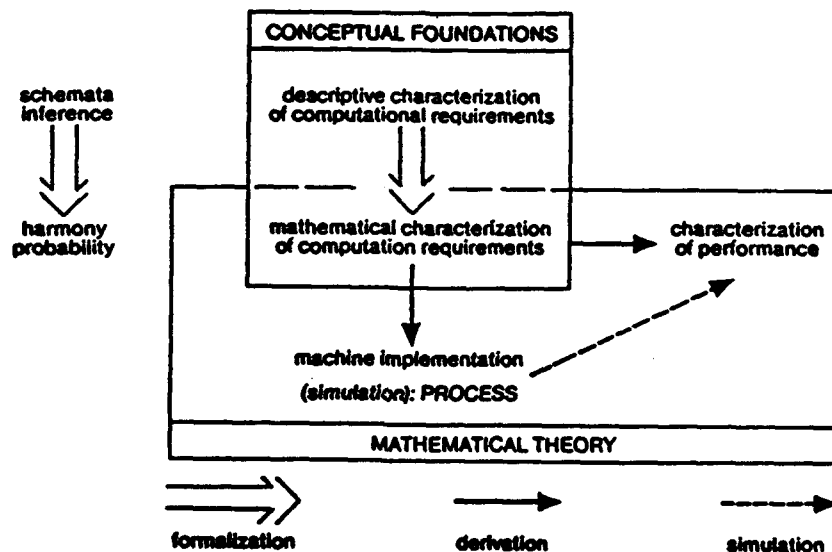


Figure A-6. Harmony theory (Smolensky, 1986, p. 208, used with permission).

### Connectionist Theory

A semantic net is a data structure consisting of nodes, significant objects or concepts, and links, indicating the relationships among nodes (Grunwald, 1986). Nodes and links correspond, in diagram fashion, to records or memory locations; links act as address codes, which send information to memory locations. A hierarchy is formed via connections that organize the knowledge of a semantic net, which allows lower nodes to inherit the properties of higher nodes. This inheritance feature empowers semantic nets; it decreases or conserves required computing space in memory and permits deductive reasoning. The handling of exceptions to rules presents one of the aspects of this theory still undergoing investigation (Grunwald, 1986). Again, connectionist approaches provided a considerable initial stimulus to the position taken in the present effort, although some modifications of this general approach are seen as necessary.

## SUMMARY

This review, although fairly extensive, has been deliberately selective. It has emphasized theoretical positions that postulate one or more aspects of cognition and information processing relevant to the overall performance model and measurement systems developed in this report. Characteristics of these historical models that have been used to develop the present performance model include

- The multiple resource nature of human performance;
- Limitations of each resource, including location and capacity;
- Energetics of the entire processing system;
- "Preprocessing" of stimuli at an early point;
- "Pre-attentive" or otherwise primitive processes involved in such preprocessing;
- Decision points, or critical "nodes" in processing; and
- Massive parallel processing and conditions during which processing efficiency can be improved (work load decreased) through some form of "automaticity."

APPENDIX B

DETAILED DESCRIPTION OF THE ELEMENTS OF THE PERFORMANCE MODEL

## DETAILED DESCRIPTION OF THE ELEMENTS OF THE PERFORMANCE MODEL

### FIRST LEVEL FILTERS

It is assumed that first level filters (4) (identifying numbers refer to those used in Figure 4 of the text) perform very early sensory analyses. These filters occur in the peripheral sensory apparatus, usually without conscious awareness. Perhaps the most primitive of these filters might be called a "pre-sensory" analyzer (4A) in that it is directed primarily to detection of the stimulus and confirmation that it has real external energy associated with it. In other words, given that the stimulus was above some absolute sensory threshold, what level of certainty exists that it was actually an external event rather than an internal one? For instance, if all that were seen was a peripheral glint, the task of filter 4A would be to classify the event as either external or internal. The result of this decision would clearly influence all subsequent decisions.

Other first level filters perform various levels of further sensory analyses. The work of Secrist (1988, 1990, 1993) is particularly useful in this area. Secrist proposes that intensity (4B) and duration (4C) of the stimulus provide a critical early analysis for determining the type of subsequent processing. If the combination of intensity and duration exceeds a certain value (again, set by the absolute physiological limits and the status of the energetic system), then processing will become "conscious" at some level. In practice, this "consciousness" could mean that the output of these analyzers will be particularly strong and will initiate second level attention allocation functions on their own. If however, the intensity and duration value of the stimulus falls below that value (although it still may be above absolute sensory threshold), then further first level filters may be called into play. These filters analyze such things as stimulus direction (4D), shape (4E), size (4F), and other elementary characteristics.

It is important to remember that until this point, everything in the attention allocation system is happening at a basic physiological level. Detectors for the characteristics postulated in these first level filters have been identified for vision and, to a lesser extent, for audition. Their operation is "automatic" in the sense that they fire or do not fire as a direct result of stimulus energy. However, it is postulated here that their output is not automatic in that sense. Rather, when a given sensory detector fires, its triggering of post-synaptic potentials depends on the energetics of the system, which depend on a variety of psychological and training factors. Thus, even though the process at this level may be "unconscious," a mechanism is postulated through which the processes' efficiency could be measured and even enhanced.

### SECOND LEVEL FILTERS

Once the preliminary sensory analyses are performed on the stimulus, it is proposed that a second set of filters (5) comes into play. These filters appear to analyze the "type" of stimulus involved. Such an early classification might determine that the stimulus consists of verbal (5A), mathematical (5B), or spatial (5C) elements. Other possible categories might include determining that the stimulus is not any of these but is simply a trigger that requires an impulsive motor response (5D) without further processing (i.e., a simple reaction-time stimulus). In any case, the function of second level filters, as suggested by the attenuation model of Treisman

(Solso, 1979), is to classify the stimulus characteristics before organizing a response. At this point, response organization per se is not involved, but this stage of processing provides basic data upon which responses will later be organized.

Each of the individual filters postulated may, in itself, further classify the stimulus. Treisman points out that linguistic stimuli may be further categorized into syllables or words. The critical point is that, modulated by the output of first level filters, second level filters begin to add a primitive level of "meaning" to the stimulus and to categorize it appropriately for subsequent processing.

Again, the "filters" in the present model act as "comparators" in the sense that they are viewed as matching a pre-existing level with an incoming level, and their output is determined by the degree of match or mismatch. The pre-existing level is determined by the energetic system and can be modified by training. Therefore, one should be able to focus on training characteristics that would directly address this second-level subsystem.

### THIRD- AND SUBSEQUENT-LEVEL FILTERS

Beyond the second level of filters, the stimulus truly begins to acquire "meaning." It is postulated that the third level filters (6) consist primarily of memory-dependent functions which map the familiarity of the stimulus to previous situations (6A) and assess its "criticality" (6B). Familiarity is assessed by how well the current stimulus configuration corresponds to previously encountered stimulus configurations. If such mapping of present and previous experience is absolute and overlearned, for instance, the output of this filter may be extremely high (leading to amazingly fast performance). If no match is found, the output might be extremely low.

Criticality refers to a "survivability-actualization" dimension. Lower levels of this hierarchy generally produce the largest output from this filter, but higher levels can be taught to produce high output. Again, each of these individual filters may contain subsystems. For instance, the "criticality" dimension may consist of separate analyzers for "safety" and for higher levels of self actualization. Of course, the feedback from this level of attention allocation to the energetic system is critically important, since the criticality dimension will be extremely important in setting the required energy levels for all subsequent systems.

APPENDIX C  
BRIEF DESCRIPTION OF THE TEST BATTERY

## BRIEF DESCRIPTION OF THE TEST BATTERY

### ENERGETIC MEASURES

This category of tests includes six procedures, which are designed to probe the individual's typical energetic response to selected situations. The situations chosen involve performance of other tests in the battery. Thus, while the person is performing a standardized behavioral test, measures in this category are also being taken. In all cases, graded demand is made on the person, and the energetic measures are interpreted as a function of the person's response to that demand.

The performance tests recommended for use while energetic measures are being taken are the divided attention and directed attention paradigms described as follows. These tasks provide for several levels of difficulty and provide the opportunity to probe different resource demands. While a person is performing these tasks, the following data are gathered and analyzed:

#### 1. Epoch Analysis of the EEG

Several 2-minute segments of the ongoing EEG will be recorded from parietal (to linked mastoid) leads. These segments will be analyzed to determine the percentage of traditionally defined  $\alpha$ ,  $\beta$ ,  $\theta$ , and  $\Delta$  waves. The difference in abundance of each type of wave during different task demand situations will provide the basic metric.

#### 2. Galvanic Skin Response (GSR)

The GSR will be measured at the same time as 1 but time locked to specific stimulus events to obtain an indication of autonomic reactivity.

#### 3. Eye Blink Patterns

Interblink intervals will be calculated and displayed as a histogram for each of the response-demand situations. These interblink intervals will be recorded from electrodes placed above and on the outer canthus of one eye. These measures should provide a sensitive indicator of the individual's activation with respect to the need for information input.

#### 4. Voice-Stress Analysis

The 10-hz micro-tremor in the voice spectrum will be analyzed to detect stress level generated by the various response demands. This measure will be obtained by requiring the person to respond with standard phraseology to certain tasks in the testing regimen (e.g., "ready for the next task").

#### 5. EEG Spatio-Temporal Mapping

This technique is a highly experimental procedure but deserves to be included because its potential reward is very high. At least 12 electrode sites will be used (e.g., bilateral occipital, frontal, precentral gyrus, postcentral gyrus, auditory reception area, and mid-parietal). The spatio-temporal activation of these areas will be studied as a function of the response demands of the tasks.

## 6. Personality Measures

At the moment, this technique is a poorly defined set of metrics. It is included because it will obviously be necessary to account for gross personality differences, since these differences continually account for at least some variance in selection tests. However, since this area of testing is one of the most studied, it will not be difficult to choose appropriate tests from the literature (e.g., internal-external locus of control). In addition, the performance tests used in this section can be analyzed from an information-theoretic viewpoint to isolate the effects of motivation, and so forth, on task performance.

## ATTENTION ALLOCATION MEASURES

The goal in this category of tests is to probe the "attention allocation" portion of the model presented previously. A series of tasks is presented, which requires the subject to time share or to make decisions at very high speed. Thus, these tests try to probe the person's ability to appropriately make all the decisions shown in the attention allocation portion of the model.

### 7. Combined Tracking and Spatial Orientation

A two-axis tracking task is presented to the subject, with a target that can rotate 360°. The subject's task is to maintain the target in the designated circle, despite a forcing function that displaces the target and a pseudo-random turning pattern of the target. Thus, the subject must not only display tracking ability but must also display good spatial orientation to remember the appropriate right-left directions of a varying target.

### 8. Complex Coordination

Traditional joystick and pedal controls will be used to permit the person to "track" a target being driven in two dimensions by a forcing function. This task, while resembling traditional psychomotor tasks, probably also taps the integration of foot and hand motor signals.

### 9. Time Sharing

For this assessment, the combined tasks of tracking and information retrieval (Sternberg Task), which are being standardized in the Department of Defense tri-service performance test battery (UTCPAB), will be used.

### 10. Perceptual Speed

This test will require the subject to scan the entire computer monitor display to encode at least five symbols. On each presentation, one of the symbols is missing. The subject's task is to indicate which symbol is missing and which position it would have occupied.

### 11. Dichotic Listening

The ability to rapidly re-direct attention has been shown to be one of the most important characteristics of skilled performers in many jobs. This skill is best assessed by a task that requires directed shifting of focal

attention from one area to another. The dichotic listening task of the UTPAB requires this type of shifting. Therefore, this task, or some modification of it, will be included in the battery.

## 12. Directed Attention

A directed attention paradigm recently developed by NTI will be used to probe a wide range of attention allocation capacities in the person. In this procedure, two or more tasks are required from the subject. At unexpected times, the tasks shift on the screen, and the subject must shift performance resources from one to the other. In other words, the subject must re-orient attention to the required task and then must switch resources to attend to that task. In some ways, this task presents an evolutionary development from the dichotic listening task described above. However, the NTI directed attention task is significantly different in that it requires the person to shift the focus of attention and the resource that is brought to bear on the task. This shifting of both focus of attention and resource creates a rich paradigm in which one can investigate the overall ability of the subject to handle such a division of attention and can study any asymmetries in switching efficiency from one resource to another. Thus, theoretically, one could assess a subject's entire capability to rapidly adjust from one resource use to another. This capability is hypothesized to be critical in differentiating a person who is above average from one who is simply average.

In this version of the battery, the following stimulus configurations will be used:

First, a spatial skill and a verbal skill will be tested. For the spatial task, the person will see two histograms on the screen, each consisting of four bars. One histogram will be rotated either 90° or 270° relative to the other. The subject's task will be to determine as rapidly as possible whether the two are identical or whether they differ in the height of one or more bars. The verbal skill will consist of a modified version of the Posner letter identification task. The subject's task will be to classify two letters of the alphabet either as both vowels or consonants, or as consisting of a vowel and a consonant. A third task will be dial monitoring in which the subject must detect a dial that exceeds a pre-defined range. The dial task is always present, but the other two tasks switch randomly. By manipulating the number of transitions that one must make from verbal to spatial and from spatial to verbal, and by analyzing these two types of transitions independently, one can obtain an estimate of the subject's ability to make such a transition.

A second version of this test will present the verbal task described with a numerical task, and the same transition time pattern will be determined. A third version of the task will present the spatial task with a continuous memory task. If, in the course of evolution of this test battery, it becomes necessary to incorporate other attention allocation transitions, it is a relatively simple task to generate additional probe tasks to be used on one side or the other of the NTI directed attention model.

## INTUITIVE PROCESSING DOMAIN MEASURES

In this section and the one following, specific measures of skills or resources are probed. Recall that, with respect to such specific resources, either intuitive or reflective processing can often employ the same resource,

the difference being in how they are employed. Therefore, there is some overlap in these two sections. However, essentially, the present section concerns the person's ability to process signals very rapidly at or near threshold. The next section involves tests in which the processing demands are measured in terms of at least several hundred milliseconds.

### 13. Backward Masking

Secrist (1990) has developed a technique in which signals are presented with varying time intervals separating them. The dependent measure is the interval that permits discrimination of the two stimuli.

### 14. The Psychological Refractory Period

This paradigm has been described by Welford (1952; 1968) and has been one of the most frequently used techniques to analyze processing stages in the laboratory. It essentially involves two meaningful stimuli, each requiring a differential response. The second stimulus is presented with a varying inter-stimulus-interval (ISI) relative to the first. The decrement in the subject's performance, as a function of the size of the ISI, is measured. Most particularly, the point at which performance of the second task "merges" with the first is taken as a single measure of the subject's capacity to rapidly process information.

### 15. Two-Flash Threshold

This test presents two flashes in relatively rapid sequence. The ISI between the flashes is systematically varied, and the point at which the flashes are indistinguishable to the subject is determined. This threshold value provides an estimate of the resolving capacity of the visual system. This test can be conducted in two ways: behaviorally and electrophysiologically. The electrophysiological technique uses the cortical evoked response to inspect the P1 and P2 latencies as they interact with each other. This technique provides a finely grained analysis of the sensory receptive capacity of the person. When integrated with the behavioral response, this procedure should permit inferences to be made concerning the subject's ability to perceptually integrate information that is available sensorially.

### 16. Critical Flicker Fusion Frequency (CFF)

This well-known procedure establishes the basic resolving power of the retina and visual system to a train of stimuli. It is analogous to the steady state evoked response measure, and the CFF measure will be used in two modes. In the behavioral mode, a simple CFF threshold will be determined; in the electrophysiological mode, the flicker stimulus will be used to generate a steady state evoked response. This response will be calculated through use of a fast Fourier transformation (FFT). Such an analysis permits determination of the apparent transmission time of the visual or cortical system. Further, since the CFF occurs at several discrete frequencies, it will be possible to determine the transmission speed of the visual system for different frequencies of stimulation. Again, differences in this function may very well index performance capability differences between the super performer and the average person.

### 17. Steady State Visually Evoked Response

See the description for the CFF.

#### 18. Auditory Brain Stem Evoked Response (BSR)

Extremely precise measures of auditory transmission time can be obtained through the averaging of signals from the auditory pathways in response to click stimuli presented at a rapid rate. Individual differences in the latency of the brain stem components are small, and there is little variability. However, it would appear worthwhile to explore such individual differences during different energetic conditions. This exploration may be done either by applying the standard BSR approach or by using click stimuli with a masking stimulus to determine what intensity of masking stimulus is sufficient to completely erase the brain stem response.

#### REFLECTIVE PROCESSING DOMAIN MEASURES

#### 19. Semantic Reasoning (Baddeley & Liberman, 1980)

A series of symbols is presented, along with a verbal description of the logical relationships between them. The subject must determine whether the logical relations described are true with respect to the presented symbols.

#### 20. Mental Rotation

This spatial orientation ability can be probed efficiently by a modification of the criterion task set (CTS) spatial orientation task. The task presents three- or four-bar histograms to the subject, followed by the same or a different histogram rotated 90° or 270°. The subject's task is to determine whether the second histogram is the same as the first.

#### 21. Item Recognition and Immediate or Delayed Memory

These functions can be appropriately tested by a version of the "continuous memory" task from the CTS and UTCB. In this task, digits are presented above and below a line. The subject's task is to determine whether the digit above the line is the same as the previous digit below the line. By controlling the number of digits preceding the immediate one that must be recalled, complex interactions between immediate and delayed memory, as well as item recognition, can be assessed.

#### 22. Short-Term Memory or Retrieval

This test uses a paradigm proposed by Sternberg (1969) to probe short-term memory retrieval processes (including sensory or perceptual and motor functions). It involves determining whether a "probe" letter of the alphabet is a member of a previously briefed target set.

#### 23. Semantic Memory

Originally described by Posner (1978), this test requires subjects to classify letters of the alphabet according to a physical identity rule or a semantic classification rule. This test probes higher verbal processes.

#### 24. Simple Tracking

The test employed here will be a modified version of the sub-critical tracking task described by Jex, McDonnell, and Phatak (1966). Although it is not clear whether this simple psychomotor skill will

differentiate among pilots, it is desirable to try the test in view of its simplicity and face validity.

#### ADDITIONAL MEASUREMENT DIMENSIONS OF THE BATTERY

The candidate tasks in themselves constitute a comprehensive survey of the theoretically important points at which people of different job-critical skills should differ. They should certainly isolate any differences that exist. However, additional procedures can be introduced which permit manipulation of the tasks to provide even richer analyses. For instance, it will be possible to manipulate the reward payoff for each task systematically, thus making it possible to "sweep out" a full set of POC curves to determine the  $d'$  and  $\beta$  functions. The effect of motivation, intent, and physiological fatigue can therefore be isolated.

In these tests, interest will not only be in the absolute level of performance that the subject reaches but also with such things as learning curves, strategy changes, and response inhibition. It is suggested that the portions of the battery deemed relevant to a particular job category be given several times over a several-day period. The subject's acquisition curve over that time period will then constitute an additional valuable set of data.

Characteristics of those curves, such as reliability and differential stability, will be determined over the entire learning period of each test. Techniques will also be developed to "flag" atypical patterns in a person as training proceeds. This procedure will therefore incorporate corrections for "faking," "cheating," or other atypical performances on the part of a subject.

APPENDIX D

EXAMPLE OF THE TRAINING SYSTEM RELATED TO COMMAND AND CONTROL TRAINING

## EXAMPLE OF THE TRAINING SYSTEM RELATED TO COMMAND AND CONTROL TRAINING

### OVERVIEW

To provide a broad perspective of how the training concepts developed in this Phase I SBIR could be applied to actual tasks of interest to the Army, this appendix addresses one prototypic area of crucial importance to U.S. Army combat C<sup>2</sup> effectiveness: command and control (C<sup>2</sup>). In view of the scope of the present effort, only an abbreviated version of the technical approach is presented in this section. However, this version should be sufficient to allow the reader to visualize how the overall model and nonlinear approach can be implemented.

This section addresses several main areas of the technical approach as follows:

1. Perspective and rationale of the proposed technical approach including the important linkages between C<sup>2</sup> system requirements and human performance and skills.
2. C<sup>2</sup> mission analysis including tasks and task elements that might be targeted for enhancement training.
3. C<sup>2</sup> training system development encompassing principal objectives, relevant skills, development strategy, and training paradigms that guide the development process.
4. C<sup>2</sup> training system preliminary definition and configuration including training protocols, custom software, and hardware architecture.

### PERSPECTIVE AND RATIONALE

#### Nature of Combat

U.S. military forces must be prepared to fight in any type of conflict or war, anywhere in the world, and win. Contemporary political and humanitarian considerations are such that U.S. forces must be able to win quickly and decisively, regardless of the nature or potency of the threat posed by a potential adversary. The requirements of the Department of Defense Air-Land Battle Doctrine provide an excellent example of the challenging nature of U.S. Army combat missions.

The Air-Land Battle Doctrine originated by the U.S. Army during the 1970's continues to be a core mission requirement (Miller & Foss, 1987; Rhodes, 1989; Romjue, 1984; Skinner, 1989; Vought & Vasile, 1987). This doctrine represents a tripartite view of the battlefield in which three battles are waged concurrently: the close-in battle in the region of the forward line of troops (FLOT); the rear area battle against C<sup>2</sup>, logistics, fuel, munitions, and so forth; and the deep battle against second echelon and other ensuing forces. Initiative, maneuverability, and precision firepower are employed to counter numerical superiority and destroy, isolate, or divide adversary forces. The successful employment of air-land battle strategy requires exact timing, highly integrated tactics, complex decision making, and precise orchestration of the actions of component forces.

## The Importance of Command and Control

Modern warfare places a premium on the speed and effectiveness of decision making. Decisions must be based on reliable information and an accurate assessment of the combat situation; decisions must also be communicated in a clear and timely manner to those responsible for executing the decisions. Success in combat is critically dependent on the quality of leadership decisions. Effective, timely decision making is the essence of command and control.

Halberstadt (1989) concluded, as a result of his experience at the U.S. Army's National Training Center, Ft. Irwin, California, that the character and intellect of opposing commanders have profound influence on the outcome of battle. A commander's talents and the capacity to bring these talents, skills, and character to bear in combat largely determine the effectiveness of the command and control system. For this reason, C<sup>2</sup> is often described as a "center of gravity" that is given the highest attack priority in combat, and worth destroying through any means available (Warden, 1989).

Both the importance of C<sup>2</sup> and the difficulty of exercising C<sup>2</sup> escalate as combat intensifies. As battlefield conditions become more severe, effective C<sup>2</sup> increases in importance, while becoming more difficult to achieve. During combat, C<sup>2</sup> is a high priority target, and attack against all major components of C<sup>2</sup> can be expected: sensors, intelligence, reconnaissance, communications, and command personnel. Thus, C<sup>2</sup> must function with degraded assets, which significantly increase the work load on the individual at a time when shock, confusion, and disorientation are at a maximum.

Although the operational effectiveness of C<sup>2</sup> is a function of both its human and technological components, the human component is the most critical part of the system. Humans are more adaptable and can maintain effective performance in the face of rampant situational dynamics, but humans are also more vulnerable to performance degradation during combat conditions. This susceptibility to performance degradation is exacerbated by fatigue and extreme environmental conditions. Moreover, performance is degraded even further by the carnage, violence, and destruction produced by advanced weaponry and the consequential human stress and shock reactions.

In recent years, the complexity of waging war has increased; the combat capability of land forces has grown; the geographical area over which C<sup>2</sup> must be exercised has expanded; the response time of advanced weaponry has decreased (Bonds, 1987; Dunnigan, 1988; Foss, 1989; Hassig, 1990; Miller & Foss, 1987). The general implications of these conditions for the human performing in a C<sup>2</sup> environment are clear and straightforward:

1. The acquisition of accurate and timely information has become even more important during modern combat conditions.
2. There is a performance premium on trend apprehension and the capacity to anticipate situational changes, including a keen sensitivity to changes in battlefield conditions and immediate grasp of the meaning and essence of a rapidly changing combat situation.
3. Decision-making skills, including speed and flexibility in determining appropriate tactics and weaponry, have become even more important.

4. Finally, the ability to communicate concisely, unequivocally, and with sufficient lead time to be effective can be decisive in the outcome of a battle.

#### General Relationship to the Performance Model

The global analysis of the C<sup>2</sup> environment leads to the conclusion that superior performance demands several generic capabilities. When the performance model shown in Figure 4 is overlaid on the demands, it is possible to begin to establish these linkages.

First, C<sup>2</sup> performance demands a heightened awareness of the external stimulus field. This heightened awareness translates to increased and task-appropriate sensitivity of the early sensory and perceptual filters in the attention allocation system.

Secondly, the superior performer must demonstrate not only early acquisition of cues but an effective discrimination of those cues that are performance relevant. Acquisition and discrimination of cues frequently involve accurate assessment of the combat situation from minimal information. Thus, later filter levels of the attention allocation system come directly into play, especially those concerning template matching, and the initiation of "automated" decisions and actions based on extensive prior mapping between stimulus-response situations. A third requirement is effective decision making during great urgency and stress. This ability requires efficient use of the energetic system, especially as it is affected by "psychological" factors. Thus, feedback from the attention allocation system to the energetic system becomes highly critical in this environment.

The general human performance requirements may be considered critical, if not unique to the C<sup>2</sup> environment. Of course, other situation-specific skills are also critical. Taken together, these requirements demand and begin to define, training approaches and systems that can inculcate and enhance highly skilled performance behaviors in the soldier. In the next section, the specific missions and tasks of the C<sup>2</sup> environment are examined in more detail to further define such training systems.

#### EVALUATION OF MISSIONS AND TASKS (C<sup>2</sup>)

##### Mission or Task Analysis

A preliminary analysis of U.S. Army missions and constituent tasks was conducted using the data developed by Rigg, Harden, and McFann (1985). The analysis was done using mission and task selection criteria that gave precedence to (a) C<sup>2</sup> tasks that are central to U.S. Army core missions (infantry, artillery, and armored cavalry), and (b) C<sup>2</sup> tasks that are more difficult to learn efficiently using traditional training approaches. The missions and tasks that appeared most appropriate for enhancement training are presented in Table D-1.

##### Task Analysis Process

The C<sup>2</sup> tasks presented in Table D-1 constitute the beginning of the analysis process for the design of a training system. The next step involves an analysis of these tasks with respect to the types of processing required by

each task, based on the performance model. Such analysis and scaling focuses on four major factors that constrain or delimit perceptual and cognitive performance: (a) the state of information during the period of optimum information acquisition, (b) the form of the information acquired; (c) the time-urgency demands impinging on the mental operations (perceptual and cognitive) involved in the requisite information acquisition, processing, and decision activities; and (d) the level of stress inherent in the task demands and situational context. These factors are discussed briefly in the following paragraphs.

#### Informational State

The issue of timeliness in information acquisition concerns the extent to which performance depends on acquiring information early in an emerging near-threshold state. The time lines issue also relates to the relative importance of subtle cues and whether performance-relevant information is present in a low intensity, short duration (fleeting) state.

#### Information Form

Information form refers to whether task information is acquired and processed in primarily a spatial or patterned form vis-a-vis linguistic or symbolic form. Another important dimension of form is the extent to which information is concrete vis-a-vis abstract.

#### Urgency Demands

The temporal dimension concerns the time urgency associated with five stages of information processing: information acquisition, information integration, problem or situation assessment, decision, and response execution.

#### Task and Situation Stress

The existence of task-generated and situation-related stress introduces additional impediments to superior performance. The scales and templates developed from these analyses are used to assess the amount and criticality of each resource demand associated with the candidate mission tasks and task elements. In other words, the specific tasks presented in Table D-1 are described in terms of the amount and criticality of each of the elements of the model. This table establishes the elements of a training system for that particular Army task.

#### TRAINING SYSTEM DEVELOPMENT

The next general stage in the development of a training system involves selection of appropriate techniques for enhancing the soldier's skills in those areas of performance identified as critical to that particular job. In other words, rather than general "skill" training or a shotgun training approach, an attempt is made to train the required functions with almost surgical precision. The selection of "appropriate" techniques is, of course, critical, and this section discusses some general principles for such selection within the C<sup>2</sup> framework.

Table D-1  
U.S. Army Missions and Tasks<sup>a</sup>

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INFANTRY C<sup>2</sup>

- Mission E: See battlefield during battle  
Tasks selected: 2  
1. Identify critical combat information and intelligence  
2. Analyze enemy force
- Mission F: Control and Coordinate Combat Operations  
Tasks selected: 3  
1. Modify scheme of maneuver  
3. Supervise execution  
4. Maintain the battlefield
- Mission G: Employ fires and other combat support assets  
Tasks selected: 2  
1. Modify fire support plan  
2. Employ fire support
- Mission H: Concentrate or shift combat power  
Tasks selected: 4  
1. Determine critical place and time  
2. Concentrate or shift combat powers in the attack  
3. Concentrate or shift combat power in the defense  
4. Protect thinly held areas
- Mission J: Secure and protect the battalion  
Tasks selected: 2  
6. Detect or impede threats to battalion security  
7. Detect or defeat enemy air assets
- Mission K: Troop leading during the battle  
Tasks selected: 1  
1. Supervise compliance with battalion order
- Mission L: React to situations requiring special actions  
Tasks selected: 4  
1. React to enemy electronic warfare  
2. React to chemical or biological attacks  
3. React to nuclear attack  
4. React to loss of key member of command group

ARTILLERY C<sup>2</sup>

- Mission C: Command and control delivery of field artillery  
Tasks selected: 2  
1. C<sup>2</sup> Battalion delivery of fires in the offense  
2. C<sup>2</sup> Battalion delivery of fires in the defense
- Mission E: Command and control battalion maneuver operations  
Tasks selected: 2  
1. C<sup>2</sup> Maneuver operations in the offense  
2. C<sup>2</sup> Maneuver operations in the defense

ARMORED CAVALRY C<sup>2</sup>

- Mission A: Plan and control combat operations  
Tasks selected: 6  
5. Plan direct fires  
10. Maintain orientation  
11. Control unit maneuvers and fire (measures)  
12. Control unit maneuvers and fire (signals)  
15. Control direct fire  
16. Control fire support
- 

<sup>a</sup>Mission and task data extracted from Rigg, Harden, and McFann (1985). Mission letter designations and task numbers are the same as those used in the Rigg et al. study.

The general paradigm for C<sup>2</sup> training merges four advanced performance models: attention, energetics, intuitive processing (HP-I) and reflective processing (HP-II). A description of the theoretical and methodological implications of these models is given below.

#### Attention Model

The attentional processes comprise a pivotal linkage and triggering gate in determining the relative activation of the response domains. These processes influence information acquisition and the consequential relative activation of the major response domains. O'Donnell (1990b) has elaborated the attention allocation process in some detail and has developed a versatile set of testing and training techniques postulated to tap attention allocation resources as well as the capacity to rapidly shift attention. These techniques require a person to input and process specific kinds of data about specific schedules determined by the testing and training regimen.

Using such approaches, it will be possible to target specific nodes of the performance model for training (sensory input, perceptual processing, etc.). These techniques can then be learned individually, and simultaneously, to enhance the person's capability in components critical to the specific Army task.

#### Energetics Model

The energetics model is concerned with measuring the overall internal energy state of the individual. The goal is to index internal energy states to the information acquisition, processing, and decision performance of people accomplishing tasks.

With regard to attentional focus, the situational awareness research (e.g., Secrist & Hartman, 1993) suggests that heightened awareness of the external stimulus field is facilitated by

1. A state of alertness that can best be portrayed as one of relaxed attentiveness.
2. Regulation of the attentional processes in a manner that balances two competing requirements: (a) the demand for focused, selective, narrow band receptivity tuned to the task; and (b) the need to maintain a relatively unfocused, global, broadband receptivity with respect to the entire stimulus field.
3. Management of internal state energetics in a way that maintains a low level of arousal and minimizes internal noise to increase sensitivity to near-threshold information in the external environment.

Thus, there is substantial research evidence that distinguishable and differential states of alertness, attention, and internal climate appear to differentially accompany and facilitate superior performance in the differing response domains of the model presented in Figure 4 (Dixon, 1981; Secrist & Hartman, 1993). This realization has heightened interest in internal states and corresponding energetic mechanisms.

Several techniques for measuring internal states and underlying energetics have been identified (O'Donnell, 1990b; 1991b; O'Donnell &

Eggemeier, 1986), and a set of metrics for an energetics assessment module has been proposed. Using a feedback mechanism for training the person to optimize this internal state, the training module will be able to tailor the desired state to the required performance.

#### Intuitive Processing (HP-I) Model

HP-I theory and training methods as applied to U.S. Army C<sup>2</sup> will concentrate on achieving three objectives:

1. Heightening awareness of performance-critical information within the combat environment.
2. Increasing the speed and accuracy of battlefield situation assessment.
3. Enhancing the speed, reliability, and validity of combat decisions.

The intent of the HP-I training methods is to drive relevant perceptual and cognitive processes to respond to increasingly challenging and urgent situation assessment and decision requirements. A key premise of the training approach is that HP-I skills can be developed and enhanced by (a) increasing the speed and accuracy of constituent mental operations and (b) strengthening the resolving power and functional efficiency of related perceptual and cognitive processes. The methods by which these goals are realized involve intense training with authentic task content during escalating information acquisition, processing, and decision demands.

#### Reflective Processing (HP-II) Model

The HP-II requirements emphasize higher order thought processes such as inductive reasoning, inference, abstract and symbolic processing, complex categorization, relational transformations, and so forth. Since the HP-II model represents the mainstream of contemporary behavioral sciences research and technology, further elaboration is unnecessary. The traditional data base and associated conventional knowledge of HP-II have been integrated into a descriptive model by Shingledecker, Crabtree, and Acton (1982), and have been further refined to attain an advanced HP-II assessment battery. Again, this battery can be used in both a training and assessment mode to enhance a person's skills in specific areas of function.

#### SUMMARY

In this appendix, a brief conceptual description of the process by which the proposed model and training concepts would be applied to a specific Army task has been presented. This process involves, first, an analysis of the missions and tasks associated with a particular task. Secondly, these tasks are analyzed with respect to the processing sequences and domains postulated in the performance model and the degree to which each domain is required by the task. Finally, training tasks matched to each of the performance sequences and domains are integrated into a customized training "module" for that particular task.

This approach is, of course, not radically different from traditional approaches in many respects. However, several significantly innovative aspects are proposed. First, the model itself is nonlinear and provides considerably more flexibility in defining "optimal" performance strategies. Thus, training options are broadened. Secondly, the model emphasizes early "pre-cognitive" processes, which have largely been ignored in traditional training. Third, the specific training tasks included for the attention allocation, energetics, and intuitive processing nodes are non-traditional. They represent generic training techniques, which (in different combinations) are hypothesized to be applicable to many specific Army skills. Taken together, the approach described here provides a genuinely novel technique for enhancing soldier performance in practical situations.